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PREFACE

In these days when technical instruction is coming so much to the front, the need for that instruction to be as practical as possible is ever becoming more acutely felt. There has sprung up a great body of experimentalists of all ages and of varying ability who, desiring to keep abreast with modern science, construct various forms of apparatus to satisfy their mechanical inclinations. That this is no mere novelty of more or less transient existence, but an ever-growing hobby and in some cases a semi-profession, is clearly proved by the existence of flourishing periodicals whose columns cater for these individuals, a rapidly increasing supply of literature on practical, scientific, and engineering subjects, and, more striking still, the steady growth of commercial houses where the necessary materials, tools, etc., may be obtained.

Perhaps no branch of science is more popular than the electrical, and with the increasing use of this mysterious agent this is not to be wondered at.

Competition in modern life makes it imperative that the young man entering the world of science, or as a mechanician, should be as well equipped, both in theory and practice, as is possible. To this end we have flourishing technical institutes where he may in spare time receive the instruction he needs. The author, as a teacher of some years experience and a life-long experimentalist, believes, however, that a good deal of time could be saved and a better foundation secured if the boy at school, whose love of things mechanical leads him to construct models, etc., could be induced to proceed in a definite path and with more method. To this end the author has prepared this little volume. It contains descriptions of a variety of apparatus which the veriest tyro could construct, and while the tools and materials required are of the simplest, the knowledge obtained by the construction and subsequent use of the various pieces of apparatus will be such as to afford a general groundwork of things electrical with an increasing ability in the actual mechanical manipulation.

No claim is made for originality in the greater part of the models, but simply a classification in definite order of many well-known forms of apparatus, and their adaptation to the skill of the young amateur. Although the writer had in mind chiefly *young* amateurs, he is well aware that a good many older members of the fraternity will peruse these lines, and hopes they may find as much to interest them as those of less mature age. In fact, the book is dedicated to "beginners of all ages." Suggestions and ideas have been obtained from many sources, especially from the volumes of *The Model Engineer*; but it should be borne in mind, however, that every example set out for the reader to construct has actually been made by the author in order that constructional details could be confidently given, and that the reader should therefore be able to produce satisfactory results with the minimum possibility of failure.

The book is not intended to supersede the text-book or laboratory, but to be an accessory to both; and if the reader should find that he obtains pleasant occupation and instruction from its perusal, the author will feel that his efforts have been justified.

ALBERT V. BALLHATCHET.

London, S.W.

NOTE *RE* ILLUSTRATIONS

It will be noticed that the titles under the photographs in this book are in each case followed by a figure in brackets, to indicate the approximate scale of the photograph. Thus the figure ($\frac{2}{5}$) after the title of the frontispiece means that the photograph is approximately two-fifths of the full size of the apparatus illustrated.

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CHAPTER I

INTRODUCTION

IT is proposed in this chapter to give the reader a few hints on the method of working.

He should procure a good elementary text-book on electricity, which need not be expensive. There are a great many on the market, and the reader must be guided chiefly by the extent of his means, for the author does not desire to specify any particular work. Of course, if the reader is a student at a school or institute, he will, without doubt, be recommended the particular text-book which is in use by the members of his class. In following the course here laid down he should first read up all the matter pertaining to the section in hand, taking particular notice of any experiments described, noting especially the apparatus mentioned. If any calculations are given he should try to master them and get as full an understanding of the theory as possible. Very little theory is introduced in this book, for the aim of the author is to give the earnest student sufficient instructions for him to be able to produce, by his own efforts, apparatus which, while simple, should be typical of the high-class instruments generally forming the equipment of a good laboratory, and yet capable of affording him sufficient practice to verify his theoretical knowledge. Having proceeded with the theory, the next step is to work the experiments. In order to do this he must first construct his apparatus. Full and detailed drawings are provided, and these, coupled with the illustrations and very plain instructions, should make matters quite straightforward. If the reader has done little manual work he must be prepared to find his early efforts produce clumsy-looking results. It may be, perhaps, that he will have to scrap certain parts and try again; but that is all part of his education, and if constant perseverance is applied success is sure to follow. He should not be in too great a hurry to produce the finished article, but take time to consider, and turn out each portion to the best of his ability. Finish and neatness will come in due course.

Another extremely useful practice will be for the worker to produce full working drawings before proceeding with the actual construction. These should be reproduced full size from those given in the text. Instructions as to drawing are easily obtainable from other sources, so the writer did not think fit to devote any space to that subject here. The importance of being able to produce and understand them cannot be overrated, and as much practice in this direction should be obtained as time and opportunity will permit.

When a particular portion of apparatus is completed, the experiments should be worked. Each step should be carefully jotted down in a notebook, the calculations, if any, made, and the final results entered up. If things do not result as expected, go through each step again, endeavouring to ascertain where the error lies. Then, with the text-book as reference, try to fit in the theory with the practical results, and do not leave that phase of the work till all is quite mastered.

The really earnest student will find plenty of scope for his ingenuity, for in the greater part of the constructional work plenty of latitude can be allowed as the tools or materials he may have at hand may not exactly lend themselves to the precise description here given. This, provided the main principles are followed and a little common sense brought to bear on the job in hand, will produce results, generally speaking, as well as an exact reproduction of the prototype would give.

No chance should be lost of giving a thorough examination to a professionally made piece of apparatus. Here will be found the best materials and workmanship combined with fine design; and the amateur should find plenty of hints as to mechanical detail, and a degree of perfection at which he may well aim.

The co-operation of another worker is also a great help, as the work is lightened and those little difficulties which are almost bound to crop up can be discussed until they are dissolved. The old saying that two heads are better than one will be found to be very true. Of course, it may be that the worker has already in his possession some forms of apparatus which will or can be made to serve; or he may even be inclined to purchase them ready-made. This will no doubt save him some time and trouble, but the writer feels certain that the student who determines to work conscientiously through the course, making all for himself, will derive far more educational gain and infinitely more pleasure by so doing. Many other forms of apparatus will no doubt suggest themselves to the worker, and he should lose no opportunity of scheming out ideas of his own. The field he may cover is very large, and the examples set out in this book are but types of well-known instruments and appliances modified to suit the beginner. The possibilities of such work are almost limitless.

Finally, the writer strongly urges the reader to become a regular subscriber to periodicals such as *The Model Engineer* and *Junior Mechanics*, in whose columns he will find abundant food for thought in the form of hints as to tools, materials, and methods; descriptions of new apparatus, and also of many pieces made by amateurs like himself; accounts of how they overcame their difficulties, as well as articles and answers to queries by a staff of experts.

CHAPTER II

EQUIPMENT

THE equipment necessary for the amateur's workshop falls naturally under two heads:—Tools and materials.

The question of tools is really a difficult matter to settle, for not only does the consideration of the amateur's means arise, but also the capability of the individual; one being able to produce splendid work with what another would consider a hopelessly inadequate kit of tools. We have all heard of the marvellous productions of workers who have used only a penknife and a file; but while the author confesses to being a little suspicious of these statements, he must acknowledge that some persons do turn out work that seems incredible when considering the small amount of tools they use. On the other hand, some do not seem to be able to produce anything like good work even with a splendid range of tools. The personal element undoubtedly counts for a good deal. Then, again, it may be that the reader has a fair number of tools commonly found in the household, so if the author gives a general idea of what is necessary, indicating a few essential items, the student will be able to form a good idea of what he wants for a commencement at any rate. He will, of course, be able to supplement to any extent as he feels inclined or is able to afford.

It will be seen that the range of apparatus involves a fair amount of woodwork and perhaps a little more metal work. The woodwork is not heavy, and the most ordinary tools will suffice, the following being the chief:—Hand and tenon saws, with a bow or strong fret saw in addition if possible; a brace and set of bits, some chisels of various widths, and one or two bradawls. A plane is also a necessity, and the author would suggest a jack-plane, and also an American block-plane for light work. A marking-gauge and try-square can hardly be omitted, while a screw-driver will be wanted, and of course a hammer. It may be possible to make one hammer do, and if so this should be one with a ball-pane, as this form is most suitable for metal work. A glue-pot is also indispensable and should be of fair size, as it is most annoying to run short of glue in the course of a job. Other tools which might be added, if circumstances permit, would include a spokeshave—not too large—and a couple of G clamps. No mention has been made of an oil-stone. This is, of course, essential for keeping the plane and chisels in good cutting trim.

Now, with regard to the metal-working tools, perhaps the amateur's thoughts will first turn to a lathe. If he possesses one he is fortunate, but the author can assure him it will not be by any means a necessity. The whole of the work mentioned can be performed without one. Indeed, the apparatus was so designed. In these days when small turned parts are sold so cheaply, it does not pay the amateur to make them himself except for the practice involved in their construction. The writer confesses at once to having used a lathe very often in the construction of some of the apparatus, but this was done simply because he had a lathe at his command, and it would be rather foolish to refuse its aid simply to prove that it could be dispensed with. The only portion beyond pure turning where a lathe would be of great help would be in drilling the metal parts; but if the student will supply himself with one of the small geared hand-drills sold at four or five shillings, he will have an exceedingly valuable aid; indeed, very small turning is not at all impossible with one. A set of twist drills with this will cover all his needs for drilling purposes The sizes should be from $\frac{1}{16}$ in. to $\frac{1}{4}$ in., rising by 32nds, this giving seven as a total number, and they are not expensive. More can be added as desired. Files should include a bastard and second cut, 6 or 8 ins. being quite long enough. One or two smaller ones could, of course, be added with advantage. A hack saw the author considers indispensable, and this, with the addition of a small pair of snips, will complete the metal-cutting outfit. Another item which can hardly be excluded is some form of screwing tackle. A screw plate with taps may be obtained, although it will be found that the now popular circular dies, with their accompanying stock, are really better, not only from the fact that they are mechanically superior in that they produce better threads and are adjustable, but also that, being interchangeable, either the Whitworth or B.A. series can be used at will, and extended in range as desired. If the necessary sizes are purchased with the taps (taper) to match, the price will be found to be about the same as for a screw plate. A small cold chisel will be found useful, while for an anvil an old flat-iron mounted in a wooden block will serve quite well. One or two pairs of pliers are necessary, and of course a soldering outfit is equally so. The vice can be as good as means will allow, the parallel type being best suited for light work such as the amateur will undertake; but at any rate he is advised not to buy a very cheap one, as these soon get quite unreliable. It is far better to pay a fair price at once and get a really good article that will give many years' service.

The most difficult matter on which to advise is the work bench. A good many readers will probably do their work in one of the living-rooms of the house. Here anything like a heavy or permanent bench is out of the question. In this case the domestic table could be used, provided it is fairly strong; and the writer suggests a false top being used. This might be a stout plank 9 or 10 ins. wide, and if provided with a batten on the under side at either end, the space between being the length of the table top, this plank can be laid on when wanted and will be firmly held in position. The vice could be fixed at one end, and near the other some form of bench stop rigged up so that planing could be comfortably undertaken. This form of bench precludes the use of a bench vice for woodwork, but, on the other hand, it will be found that this is by no means a necessity. The writer much prefers the ordinary vice for the wooden portions, two strips of thin wood or even cardboard being used as clams to prevent marking. None of the woodwork being very large, this method will answer very well. If the worker has a workshop to himself he can erect a permanent bench; but it need not be elaborate by any means, the chief considerations being rigidity under all strains, that it is of convenient height and not too narrow; a couple of 9-in. planks, 2 ins. thick, mounted on a good foundation serving very well.

No mention has been made of the method of using the various tools, as it was felt that such information does not come within the scope of this book. If the amateur is unused to tools, he must obtain one of the cheap little handbooks on the market, where he will find plenty of help. Or he might be able to get a few hints from a friendly artisan of his acquaintance. Only one other word of advice need be given, and that is to use the tools carefully, each for its legitimate purpose, to keep them clean and in good trim, and to pack them carefully away when not in use.

Now as to materials. It might appear after a first survey of the apparatus recommended for construction that the outlay in this direction would have to be considerable. But a careful investigation will show that this is not so. As a matter of fact, several items were made almost entirely from scrap material. It is wonderful how despised and homely odds and ends can be made to serve; for, after all, the success or otherwise of the instrument constructed does not so much lie in the nature of the materials used for the component parts as in the care in construction and intelligent handling. The wood necessary, for instance, in nearly all cases can be portions of packing-cases or discarded furniture. The boxes in which the New Zealand butter comes to the market will be found to be excellent material, being straight grained, free from knots, and of good colour. In any case, when taking a box to pieces, use care so that the wood is not split; withdraw all the nails, straightening and storing them away for future use. For lighter work, prepared fret-wood can be used, and this, being already thicknessed and surfaced, requires little working up. Old metal parts of all sorts of things should be packed away in boxes after being taken to pieces and cleaned from grease, or paint, etc. Such things as old electric bells, clockwork, mechanical toys, and so on provide very convenient pieces which would otherwise have to be bought. A friendly electrician could no doubt supply quite a quantity of oddments of very little value to him, but which would prove of great service to the struggling but ingenious amateur. Occasionally a small piece of metal would have to be purchased when the scrap-box fails to provide a suitable piece. This, however, need not entail any great expense, for a neighbouring ironmonger will in all probability be able to supply the need quite reasonably. Such things as insulated wire, battery plates, chemicals, and a few other items must of necessity be purchased. The student is advised to obtain the catalogues of those well-known firms who cater for this sort of thing. Their advertisements will be found in *The Model Engineer*, and he will find them offer a splendid array of fittings and materials at moderate prices, and be assured of courteous treatment at their hands.

It may be well at this point to give a thought to the finish to be applied to the completed apparatus. The woodwork can, of course, be left bare; but it will certainly look better and wear better if some protection is given it. Here, again, the skill of the individual is a big factor. If he can manage french polishing, well and good. If not, then a coat or two of varnish will be quite satisfactory; and for the very raw beginner the ready-prepared varnish stains procurable at any oil shop will be found to give excellent results. As shellac varnish is of great use in electrical work as an insulator and also as a protection against damp, the student should always have a supply ready; and although it can be purchased, it is quite as well made at home. Shellac can be obtained at an oil and colour stores, and being light in weight, an ounce or two will go a long way. Place it in a small glass jar and fill up with methylated spirit. Cover the jar with a tightly fitting cork and leave for a few days, shaking occasionally. Solution will gradually take place, and it is then ready for use. Do not have it too thick, thinning out with more spirit as necessary. It is a good plan to let the brush used for applying it remain in it, as it (the brush) is always then in good condition, and the vexation of finding it caked hard is avoided. If a small hole is pierced in the cork, the handle of the brush can project through, and the two need never be separated. The author uses what is known at oil and colour shops as "white hard varnish" a good deal. It is a kind of shellac varnish and gives a very good finish to woodwork, and has the advantage of drying very quickly. The amateur is warned against using ordinary varnishes for insulating purposes, at least on metal work. Several cases of corrosion of metal parts have come under the writer's notice, being no doubt caused by the acid properties of the oils used in the preparation of the varnishes. Generally speaking, iron work can be given a coat or two of enamel after thoroughly cleaning from grease and smoothing up, the colour of the enamel being to the worker's fancy. Brass or copper work is best left bright, although it will gradually get dull. To avoid this and the consequent necessity for repolishing, it might be lacquered. Some amateurs find this rather a difficult process, and no doubt to obtain results equal to the professional a considerable amount of dexterity and practice are necessary. The amateur will find very good results by simply painting over the polished metal a very thin, spirity wash of shellac varnish and then placing the article in a fairly warm oven to harden off. If the heat is too great, the varnish will brown and the appearance be spoiled. It can, however, be removed by rubbing with methylated spirit. Paraffin wax is also another splendid insulator extensively used; and small wooden portions of apparatus, small coils, and the like, requiring treatment, can be immersed bodily in the wax, which should for this purpose be melted in a good sized tin, taking the precaution of avoiding too much heat, as the wax will be discoloured or may even take fire. It is not good practice to use candle ends in place of paraffin wax as is sometimes advised, as the wax used for this purpose is rarely paraffin only, and in most cases contains vegetable acids which will attack metals such as copper, the subsequent corrosion destroying them.

Such items as nuts and bolts, metal screws and terminals, should be purchased, for, as was previously mentioned, these are far better obtained ready-made than produced from stock by the amateur. They are very cheap and can be obtained in a great range of sizes and patterns.

Our list of requirements, then, is not so great as would be imagined; and if the earnest worker will exercise a little discretion and thought, he will not be at a loss to find suitable materials. The author has mentioned in describing most of the apparatus some of the scrap materials he used, or the sources from which the rough materials were drawn, and how they were converted into the required fitments. Although the total number of tools may seem great, it is not by any means suggested that they should be obtained as a whole. The amateur should add item by item as he feels the need or can afford. The main idea all through is to reduce expense to such a degree that even the most humble student may not be discouraged by thoughts of his lack of means against proceeding in the first steps of a real educational study of his favourite hobby, or, it may be, in what will be his ultimate profession.

CHAPTER III

CELLS

As the student will require some source of electrical energy for his experiments, and as the most suitable source is some form of primary cell, our earliest work shall deal with their construction.

The number of cells that has been evolved from first to last is very great, but the law of the survival of the fittest has come into play, and there are now but few of any commercial importance. Some of these latter are practically beyond the amateur's power to construct, so that those here described may be taken to represent the only types worth his consideration at present.

It must be remembered that primary cells of whatever construction, and no matter how cheaply made, are an expensive source of electrical energy, so that the amateur is not advised to contemplate any great undertaking in the way of illumination or power. Probably the only sphere in which primary cells hold their own as producers of energy is in signalling by means of bells, telegraph instruments, etc.; and even here, when a very large amount of such work has to be done, some form of mechanical production is increasingly being used.

Two operations are frequently required when dealing with the construction of primary cells, viz. the preparation of dilute sulphuric acid and the amalgamation of zinc. As these two processes need some little care, a short space is devoted to them before dealing with cell construction proper.

Preparation of Dilute Sulphuric Acid.—The strong acid can be obtained from any chemist, and is sold by weight, costing about 3d. or 4d. per lb. The commercial quality is quite good enough, and it will be found to be a heavy, thick, oily liquid. It should be kept in a bottle having a glass or rubber stopper, as an ordinary cork is soon destroyed by the acid. It must be handled with great care, as its action on animal and vegetable matter is very powerful. Should any be spilled on the skin or clothes, a few drops of liquid ammonia will neutralise its action. Some means of measuring both the acid and the water used to dilute it will be required. If the reader is a photographer or has a graduated glass measure such as used by photographers, that will be just the very thing. A small one can be obtained at a chemist's, costing a few pence, and will be found to be marked off in fluid ounces (20 to the pint). A good makeshift is an ordinary medicine bottle marked off in 12 "table-spoons," as two of these "table-spoons" go to the ounce.

When mixing the acid and water, the latter should be quite cold and measured out first. It should be put in a jam-jar as large as possible, and this placed out of doors, or in the scullery sink in case of accident. Now the acid may be measured out, and should then be poured cautiously, a little at a time, into the water, stirring the latter at the same time with a glass rod or tube, or even a narrow strip of glass. Considerable heat will be evolved during the mixing, which should on no account be hurried. When cold, the now dilute acid should be bottled off if not required for immediate use, and the bottle clearly labelled with the name and strength.

Amalgamation of Zinc.—As most cells require the zinc element to be amalgamated for the purpose of ensuring an even consumption of that metal and greater economy in its use, this process should never be omitted except in rare cases. Mercury, being expensive, should not be wasted, and the amateur will find a couple of ounces last a long time. It should be kept in a strong bottle having a well-fitting cork. As it is extremely poisonous, the hands should be well washed after using it. Such things as gold or silver jewellery (watch chains or rings) must be kept away from it, as it *quickly amalgamates with those metals, quite* spoiling them.

The zinc to be amalgamated should first be thoroughly rinsed with dilute sulphuric acid (1 part of acid to 5 or 6 parts of water). This is best accomplished by using a bit of rag tied on the end of a small stick to make a mop. When quite clean and still wet with acid, the zinc should be placed in contact with the mercury, and the best way is to use a glass or china photographic dish, or a small earthenware pie-dish may be kept for the purpose. The mercury will adhere to the surface of the zinc in a brilliant coat, which may be made to cover the whole surface by rubbing it with the mop. When the coating is complete, the surplus should be wiped off and the zinc rinsed under the tap. The mercury in the dish should then be dried by rubbing it over with blotting-paper and poured back into its bottle. It should not be used for any other purpose, as it is certain to be contaminated with zinc.

The Simple Cell.—Although of little importance from a point of utility, the student should examine the simple cell in its various forms, as it is the basis of all cells. In its original form it comprises a plate or strip of zinc and another of copper immersed in dilute sulphuric acid. A small jam-jar forms a useful vessel to hold the acid, and if of glass, permits a study of some of the reactions which take place. The plates of metal could be about an inch wide and long enough to reach the bottom of the jar. They may be provided with wires or terminals at the top and screwed to a piece of wood which is long enough to span the mouth of the jar. Fig. 1 gives an idea of what is meant. The acid is very dilute, 1 in 20 being quite strong enough. When on open circuit, *i.e.* with the plates disconnected from each other or from any piece of apparatus, the formation of gas bubbles round the zinc plate should be noted, and also their gradual transference to the copper plate when the cell is connected up and supplying current. The rapid falling off in current should also be noticed, although the beginner might postpone experiments till he has completed some form of apparatus as described later. Various combinations of elements could then be experimented upon, such as zinc and carbon, zinc and iron, iron and carbon. He will then understand more fully the meaning of the table setting out the

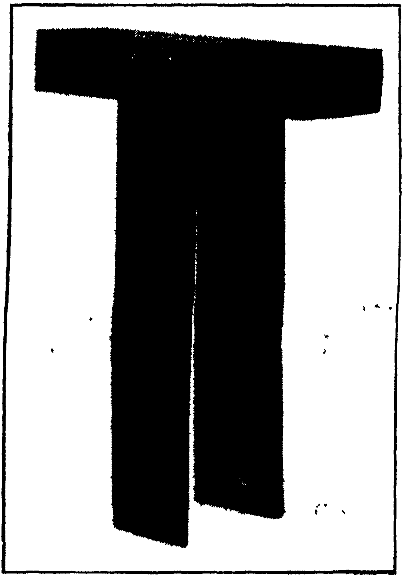


FIG. 1.—Simple Cell (zinc and copper plates). (½.)

electrical opposition of various elements, and partly why the present commercial forms of cells have their particular construction.

The Bichromate Cell.—This is a single fluid cell and the natural successor to the simple cell, being, in fact, a simple cell in which means are provided for preventing to a great extent the polarisation which is the outstanding disadvantage of the latter. Instructions are given to enable the experimenter to provide himself with a convenient and useful form of this cell. As the cell develops perhaps as much energy as any other form of cell, and is easy to construct and cheap to maintain, it is eminently fitted for the experimenter's use. As shown in fig. 2, the outfit, including solution, can be provided at the cost of about a shilling. An important feature the author has incorporated in this present form is a means by which the whole of the zinc element can be effectively used. As was previously pointed out, zinc is, so to speak, the fuel in most cells, and being, as common metals go, fairly expensive, it behoves the amateur to get the utmost return for the money spent on this element. Just as the steam engineer strives for the greatest economy in coal consumption, so the user of primary cells should study the question of zinc.

The outfit is shown comprising two cells, though three or four might be incorporated; but it will then be found to be on the cumbersome side. The woodwork offers no difficulties, nor calls for any particular mention, except that neatness and good fitting should be aimed at (fig. 3). If the maker cares to do so, the side members could be fitted

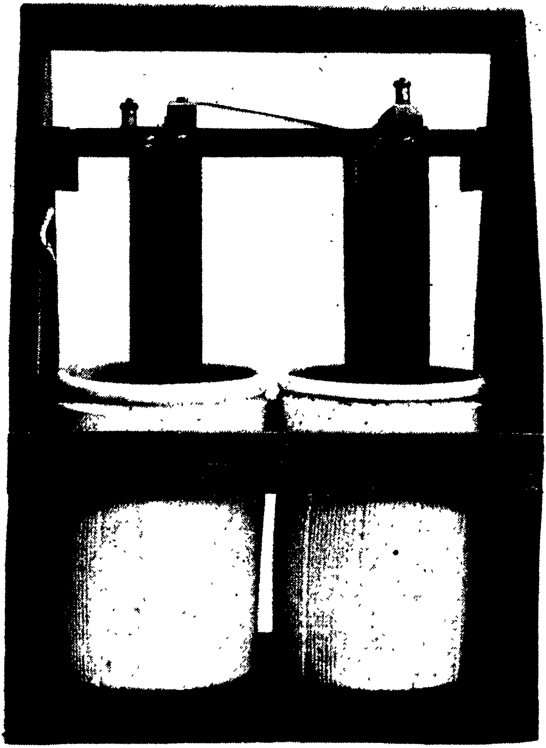


FIG. 2.—Pair of Bichromate Cells. (¼.)

with dovetail joints to the base. Any wood will do, and the finish, too, can be to the maker's fancy. The jars (jam-jars) form the basis from which the measurements are taken. Those known as No. 2 are used in the battery illustrated, being of ordinary stoneware, about 4 ins. diam. by 5 ins. high, and with parallel sides. A lot has been written about the advantages of special "vitrified" jars for battery use. The writer has used these, but, provided the jam-jars are examined to see that the

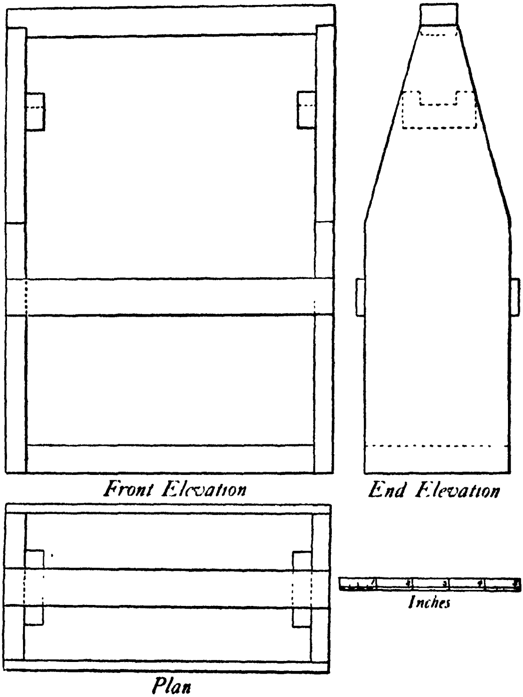

Front Elevation
End Elevation
Plan

FIG. 3.—Plan and Elevations for Bichromate Battery Case.

glaze is quite sound inside, can observe no difference in the acid-resisting qualities. Pick out those of good shape, free from cracks or dull unglazed patches, and they will serve quite well.

The carbons are easily obtained, ready drilled with two holes. They are 5 ins. long, 1¼ ins. wide, ¼ in. thick, and cost 1d. each. One per cell would do, but two are much more efficient, and the amateur is strongly advised to use that number. The upper inch or so should be soaked in melted paraffin wax for about 20 minutes, the surplus being scraped off when set. This waxing prevents the gradual creeping of the liquid through the pores of the carbon, this being the most usual cause of the corrosion often complained of. The sketch (fig. 4)

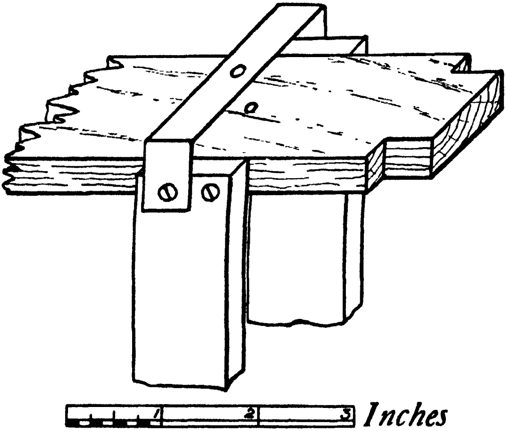


FIG. 4.—Sketch showing Brass Clamp and Connector for Carbon Plates of Bichromate Cell.

shows quite clearly the brass strips used as clamps and connectors. The screws are round-headed brass No. 5's, ¾ in. long. When screwing up do

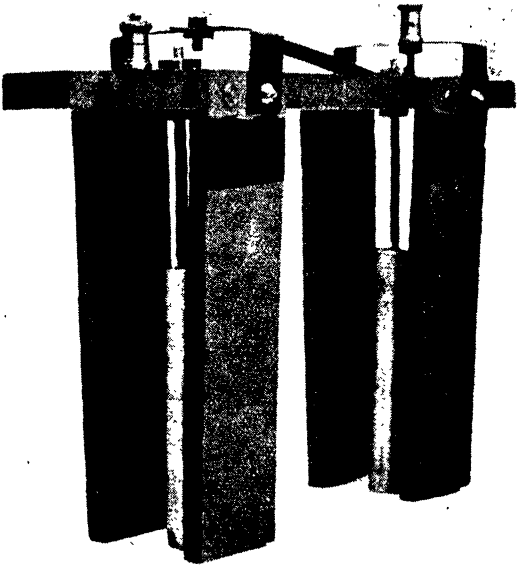


FIG. 5.—Arrangement of Carbon and Zinc Plates for Bichromate Battery. (⅔.)

not exert undue pressure, or the carbons may crack. Now the zincs. As will be seen from the illustration, fig. 5, they are cylindrical, being, in fact, halves of a Leclanché zinc rod costing 2d. or 3d. Short pieces of plate can be used if the amateur prefers, and would no doubt produce a little more current, but they must be at least ¼ in. thick. The rod form was used because it is so readily obtainable, and will be found to work out cheaper than the plate. When obtained it has soldered into one end a stout copper lead. Unsolder this by heating over the gas ring, and shake out all the melted solder. Do not take too long or you may melt the zinc. Next saw it in halves. An ordinary tenon saw will do if you have no hack saw, the metal being very soft. Up one end of each half drill a small hole to take the brass rod by which they are fastened to the wooden carrier. The brass rod is ⅛ in. diam., and it may be fastened to the zinc either by soldering or screwing. If the amateur is not fairly skilled in tapping, he is advised to solder it in as zinc has a nasty way of clogging taps, especially such a fine one as would be needed here. The upper end of each brass rod is screwed ⅛ in. Whit. for about an inch, and odd pieces of brass converted into nuts are fitted, two to each rod. The bottoms of the zincs should be about level with the lower ends of the carbons, and when the cells are in use the solution may reach to the tops of the zincs. It will be seen that consequently the whole of the zinc can be used, and when only small stubs are left it is quite easy to fit new ones, thus avoiding the waste of material. The zincs should, of course, be well amalgamated before use. When not in use the whole arrangement of carbons and zincs is lifted bodily up and supported on the two ledges provided for that purpose.

The next requirement is solution. Chromic acid is largely recommended and is very good, producing the maximum E.M.F., but will be found rather expensive. 1½ pints of solution will be about the right quantity; that is, ¾ pint to each cell. The writer makes this as follows:—¼ lb. of bichromate of potash (cost 2d.) is dissolved in 1½ pints of hot water, and when quite cool ¼ lb. of strong commercial sulphuric acid (cost 1d.) is added, bearing in mind the previous caution as to this operation. The solution is ready for use when cold.

Before setting up see that the connections are right. On one of the carbon clamps a terminal is soldered, this being the + end of the battery. From the zinc of this same cell a brass strip is carried to the carbon clamp of the other cell, and secured to it by a little nut and bolt. The zinc of this cell is provided with just a short brass strip which is fastened to the wood carrier by a terminal having a wood screw, and forms the – end of the battery. When freshly set up the pair of cells will give a current of about 1 amp. at 4 volts pressure. Of course, if the amateur so desires he may make much larger cells on the same lines, using more and bigger carbons and large zinc plates to match. This arrangement will give no more voltage per cell, but greater amperage; a condition he will find necessary if he contemplates using these cells for working a large coil or motor.

The Double-fluid Bichromate or "Fuller" Cell.—This is a very convenient and easily constructed cell, and is of great use when a fairly powerful and constant current is required to be passed for some time. It is consequently used by many who, while

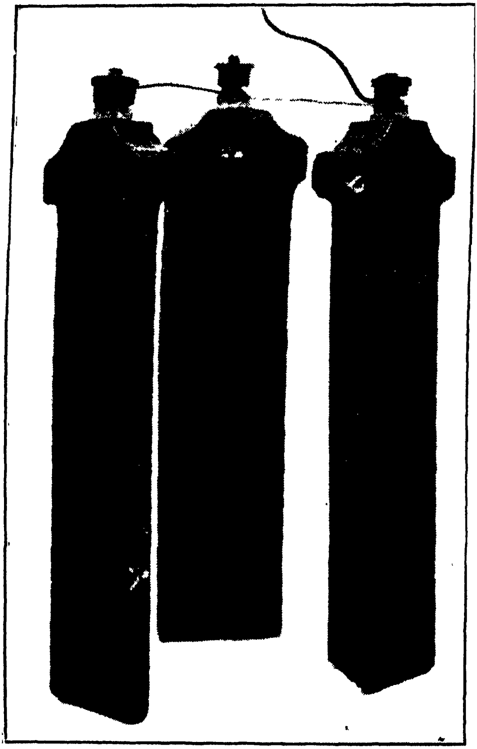


FIG. 6.—Carbon Element for Fuller Cell. (⅔.)

possessing accumulators, have no means of getting them recharged. The outer jar contains a saturated solution of bichromate of potash with about three fluid ounces of sulphuric acid added to each pint, and also the carbon element. This generally takes the form of two or three carbon plates all connected together and spaced equally round the porous pot, which stands in the centre, as shown in fig. 6. In the porous pot is placed the zinc, which generally takes the form of a rod and should be as stout as possible. Into the porous pot is poured a little mercury, sufficient to cover the bottom of the zinc rod to a distance of ⅛ in. This ensures the zinc being constantly amalgamated, and also seems in some way to enter into the action of the cell. Finally, the pot is filled to the level of the liquid outside with sulphuric acid to a strength of 1 in 12. When not in use the zincs should be removed, and it is as well to remove the porous pot also, bottling off the acid for further use. A battery of these cells could very well replace a large one of the ordinary form if heavy continuous work is required, but for ordinary experimental work of a more or less intermittent kind it will be less convenient and certainly more expensive.

The Daniell Cell.—This is a double-fluid cell with zinc and copper elements, and is made in a great variety of forms. Two forms are here described as being most suitable for the amateur to construct and of most use to him. The first consists of an outer jar containing the copper element, which should have as large a surface as possible—a cylinder of copper foil serving very well. With this is a saturated solution of copper sulphate, and this must be kept saturated. To ensure this a supply of copper sulphate crystals must be placed in the jar. In the commercial type of cell this is generally provided for by having the crystals resting on a shelf at the surface of the liquid, the fresh solution then gravitating downwards by reason of its greater density. For the amateur who cannot, perhaps, arrange matters quite so well, the crystals may be placed at the bottom of the jar, and this will be found to give pretty good results. The porous pot contains the zinc, which again may be a rod, the ordinary Leclanché rod serving very well. It should be amalgamated, but no loose mercury should be allowed to remain in the pot. The acid here can be varied in strength according to the work the cell is required to perform. If a steady current is required during a lengthy time, a few drops of acid in the potful of water will suffice; or even a fairly strong solution of zinc sulphate may be used. When not in use the cell should be dismantled entirely or the liquids will gradually diffuse through the pores of the pot. The pot should also be allowed to soak in water to prevent deposition of crystals in its pores.

The "Gravity" Type Daniell.—This cell is also very simple to construct, and presents the remarkable feature of being a double-fluid cell, but without a porous pot or other diaphragm between the liquids.

The separation of the solutions is brought about by taking advantage of the difference in their specific gravities. Owing to its low internal resistance it is of great value in certain circumstances, but of course it must not be disturbed. Neither must it be allowed at any time to remain inactive or a kind of internal action, which almost amounts to reversal, takes place. To this end, when it should be necessary for the cell to stand by, a very high resistance should be placed in circuit. A 220-volt lamp forms a very convenient method, as a very small current will pass through this and yet not be sufficient to produce undue wastage.

In its simplest form the cell consists of a glass jar, at the bottom of which is placed a spiral of stout copper wire, the outer end of which rises up near the side of the jar forming the + terminal. This rising wire must be well insulated, and a good method is to slip over it a few inches of small rubber tubing such as is used for cycle tyre valves. On the copper spiral is placed a thick layer of copper sulphate crystals—2 or 3 inches in depth being suitable. The zinc element is supported by a wooden cap or bar across the mouth of the jar so that it occupies the upper part and can be just immersed in the liquid. The best form for this zinc is a thick disc as shown in fig. 7. The amateur can easily cast them for himself from zinc scrap. Make a wooden pattern and, after well oiling it, mould it in plaster of Paris. When this is set and *thoroughly dry*, the zinc may be poured in. The scraps can be melted in a small plumbago crucible or even an iron ladle, only the heat should not be too great, and the surface of the zinc should be covered with a layer of charcoal dust. A good clean fire in the kitchen grate does very well. The illustration shows the form as made by the writer, the wire being a stout piece of brass threaded at its upper end to take a couple of nuts and simply soldered into the projecting lug of the zinc. The electrolyte used is extremely dilute sulphuric acid (1 in 80). Some advise a layer of oil being placed on top of the liquid and just covering the zinc; but the writer

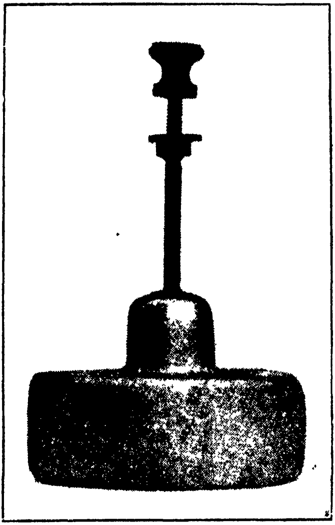


FIG. 7.—Zinc Element for Gravity Daniell Cell. ($\frac{3}{4}$.)

has never used this, and if the liquid shows signs of lessening through evaporation, just adds *very gently* a little water to make up.

A variation of the same type is illustrated in fig. 8, where the containing vessel is a wide test-tube and the zinc a short piece cut from a Leclanché rod. It might be noted, as an example of how oddments serve, that the little connectors joining the leads from each cell were obtained from some discarded electric light switches. A battery of these little

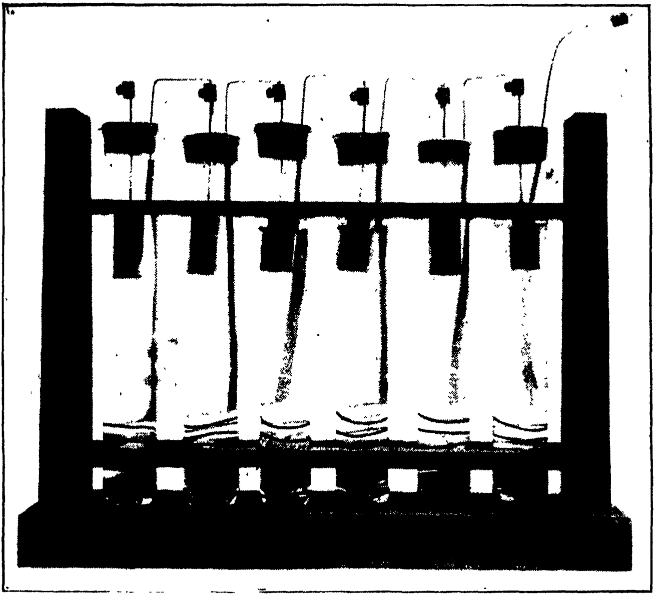


FIG. 8.—Set of Small Gravity Daniell Cells. (⅓.)

cells is very useful for testing purposes, calibrating voltmeters, etc., where only small amperage is necessary.

In addition to the uses just mentioned, the Daniell cell is very useful to the amateur in electro-plating, electrotyping, and even for charging small accumulators, the gravity type being especially suitable for this latter purpose, the only drawback being the very slow rate of charge and consequent time taken.

The Leclanché Cell.—This, in some form or other, is probably the most extensively used primary cell. It possesses the advantages of being cheap to make and maintain, and that it may be left almost indefinitely without deterioration. Its one disadvantage is the small amount of current it is capable of giving, and that for only a short time, without undergoing polarisation. The amateur is not advised to attempt the construction of the wet form, as the materials required, being purchased in small quantities, would alone cost much more than the complete cell as sold in the shops. Then, again, while a home-made cell will certainly not excel the ready-made one, it is hardly likely to even equal it in point of efficiency. The author gives, however, a little modification he has used very successfully for the purpose of supplying energy for a night-light. Three porous pots, ready charged, were obtained from the nearest ironmonger (6½d. each) and a piece of sheet zinc (No. 14 gauge) sufficient to cut three sheets, each

10 ins. by 4½ ins. These latter were rolled into cylinder shape so that they surrounded the porous pots, leaving about ½ in. clearance. To the upper edge of each a stout copper wire was soldered, and the pots themselves had about a dozen holes made in them. These holes were easily made with a large bradawl, and were spaced equally in three rows of four, thus:—⁖ ⁖ ⁖ ⁖ which would be the appearance supposing the pots to be opened out flat. A solution of salammoniac (3 ozs. to 1 pint) was then made and poured into glass jam-jars (which comfortably held the porous pots and zinc cylinders) so that the liquid came within ½ in. of the tops of the zincs. These three cells connected in series light a small Osram lamp such as is used in pocket lamps. It is rated as 3½ volts ·3 amp. and has an "S"-shaped filament. Half-an-hour's good light can be obtained without intermission, and the cells have been in use some months without attention. One caution is necessary. Some makers send out porous pots containing carbons, the heads of which are of lead. These should be avoided if possible and those with moulded carbon heads be obtained, as the lead is very liable to corrosion. If carbon tops are unprocurable, then give the lead caps a good coat of vaseline as a preventative.

The Dry Cell.—This is a very popular cell and is used in enormous numbers at the present time; but whatever their shape, size, or method of construction, they are really modifications of the ordinary Leclanché cell. The term "dry" is not strictly accurate, for if they were really dry they would be inactive. They are dry only so far that they contain no spillable liquid. Another source of misunderstanding with some users is that they can be recharged, presumably in the same manner as an accumulator. This is not so; and when a dry cell ceases to give current it is really not worth while attempting any renovation, as it may be taken for granted as a general conclusion that some essential portion is exhausted. The amateur can, however, make dry cells for himself, though he must be prepared to find their efficiency low as compared with the commercially made article. Those firms making dry cells have the advantages of the results of long experiment and special methods at their command; indeed, most of them claim some "secret" or other in connection with their particular product. Briefly, the principle of all dry cells is a zinc case, which also acts as the container, a carbon element with the space between the two packed with the depolariser; this latter being moistened with a solution acting on the zinc. Generally some ingredient is added to maintain, as far as possible, this moist condition. It will be seen that the cells can be made in any size or shape to suit a required purpose. The great point is to keep in mind that the space between the zinc case and carbon element must not be excessive, or a very high internal resistance will result. The zinc intended for the cases need not be thick, as the active material in the cell is generally exhausted before the zinc is entirely consumed. The joint must be soldered, and it is best to make a fair lap so that the solder can all be outside. The bottom can be of zinc also soldered in, although a tightly fitting cardboard disc well soaked in wax may be substituted. The writer remembers seeing one cell where the bottom was of some kind of plaster which had been thoroughly soaked in wax. The amateur maker must adopt whichever method he prefers, but there must be a layer of some insulating material on the inside of the bottom if zinc is used. This might be a piece of stout card soaked in wax, or a piece of thin india-rubber. The inside of the zinc case should now be lined to within a short distance of the top, with layers of thick blotting-paper. If only small cells one layer will suffice, but with larger cells two, three, or even four layers can be used. It should be really thick blotting-paper and of a good absorbent nature. In the centre is placed the carbon, standing on the insulating bottom. The carbon can be of plate or rod form, and one salved from an old cell will serve well, especially if it is fitted with a terminal. Now the space all round the carbon is packed with a mixture of crushed carbon and that variety of manganese dioxide known as "needle" manganese. These two ingredients should be in equal quantities by measure and of about the coarseness of silver sand. The author generally incorporates during the mixing a little finely powdered black-lead, the exact quantity not being important, about half a teaspoonful to a good double handful of the mixture. This black-lead serves to increase the conductivity of the depolariser and so lowers the internal resistance of the cell. The mixture must be put in a little at a time and *rammed* in tightly, care being taken to keep the tightness as even as possible through the whole body of the material. The level of the rammed depolariser should be just a little below the top of the blotting-paper. Now the whole of the contents can be wetted up with the active solution. The writer prepares this as follows. To ¼ pint of water which has been boiled add ¼ pint of "killed" spirit, *i.e.* spirits of salt in which scraps of zinc have been placed till no more will dissolve. In this mixture 1½ ozs. of sal-ammoniac are dissolved, and then a teaspoonful of glycerine is well stirred in. This mixture should be poured in a little at a time till no more is absorbed. The process will take some little time, and at the finish there should be no appreciably loose liquid. It is a good plan to let the cell stand upside down for any excess to drain out. Next, the cell can be sealed. A layer or two of paraffined blotting-paper is placed on top of the carbon mixture, and then the remaining space is filled with melted pitch to which a little paraffin wax has been added. A cell so made should give about 1·3 volts, the amperage depending chiefly upon the size of the cell. And here it might be mentioned, in conclusion, that a frequent source of failure in the use of dry cells is that they are often overworked. By their construction they are capable of discharging at their utmost capacity for a short time, but if allowed to do so they are soon ruined. It is understood, of course, that a fairly stout piece of copper wire should be soldered to the zinc case to form the terminal.

For further notes on the above forms of cells, and also others, the reader is referred to the "Model Engineer" Handbook, No. 5, entitled *Electric Batteries.*

CHAPTER IV

EFFECTS OF THE CURRENT

THE most self-evident effects of the current can be grouped as magnetic and thermal. After having constructed some form of cell as his source of energy, the student can next proceed to make forms of apparatus to demonstrate the conversion of that energy into magnetic or heat energy; and fortunately the apparatus so made will be of utility in many ways and on several occasions.

Perhaps the most useful form of apparatus for demonstrating the magnetic field produced by the flow of a current through a conductor is some type of galvanometer. Four forms are here described, and the student is advised to make them all, though perhaps he might leave the last until he has attained some skill in construction.

A Simple Galvanometer.—This, as will be seen from fig. 9, is simply a magnetic needle surrounded by a coil of wire. The needle is made from steel, and the writer recommends the purchase of a small scraper blade, as this provides as good material as the amateur is likely to procure, and sufficient to make

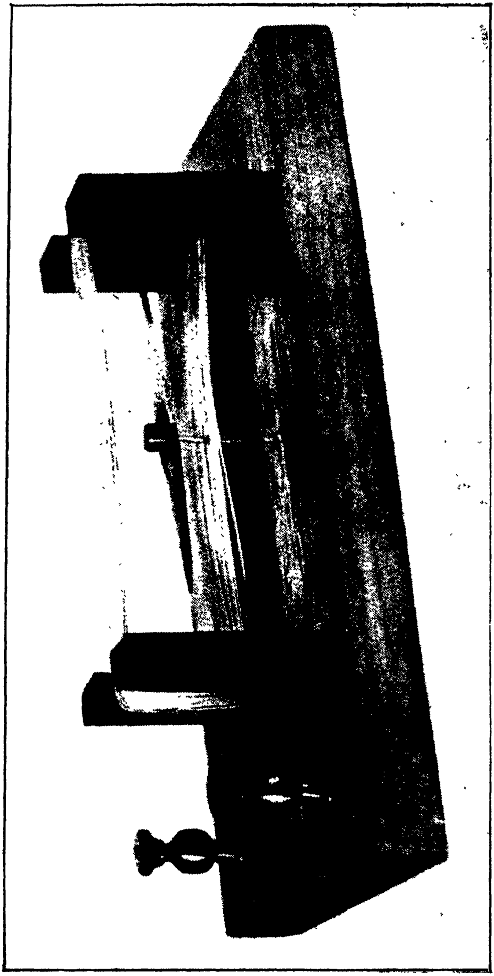


FIG. 9.—Simple Galvanometer. (⅓.)

all the magnetic needles he will require. Scraper blades are small sheets of thin steel and are used by cabinetmakers for producing a fine surface to wood previous to finishing by polishing, etc. If the steel is found rather too hard to work freely, it may be softened by heating it to a dull red and then plunging it into fine ashes or lime and letting it cool out there. Clock spring can be used, if stout, but a considerable experience in steel working is necessary to get good results, and the writer does not advise its use. The needle is lozenge shaped, though that is of little importance, simply looking a little better and being easier to balance. Cut off a strip ½-in. wide, mark the centre, and work the steel roughly up to shape. Drill a ⅛-in. hole through the centre, and then you can take the first steps towards balancing. Push a little plug of wood into the hole and make a deep dent in the end. Now try to balance the needle on a pin point, and as you proceed to obtain the finished shape, keep testing until the needle rests horizontally on the pin. Next, it must be hardened, and it must be as hard as we can get it, as it then retains its magnetism better. Loop a piece of wire through the centre hole and place the steel in a good, clear fire until it is *dull* red-hot all over. Now lift it out quickly and drop it into cold water. A better method is to lay the piece on a small strip of tin, and, using this as a handle, obtain the dull red heat over a gas ring. You will be better able to control the heating this way. The steel will now be "dead" hard, as it is termed, and very brittle, so that it must from now be handled with care. It will be almost black, so should be polished up nicely with emery cloth, using a coarse grain first and finishing with the finest you can get. Now the cap can be fitted. Take a short piece of $\frac{3}{16}$-in. brass rod and shoulder down one end for about $\frac{1}{8}$ in. a tight fit in the hole. Pass this through and well rivet it over, only be careful not to strike the steel or it will crack. There is no need, either, to continue the riveting after the brass is holding sufficiently to prevent it turning. Now cut off the projecting $\frac{3}{16}$-in. end, leaving about $\frac{3}{16}$ in., and finish off to a rounded top. Centre punch the riveted side and drill a $\frac{1}{16}$-in. hole nearly through the cap, keeping the hole quite central. Try for balance once more, this time on a fine sewing-needle. If necessary, the heavier end must be lightened by cautiously grinding the under surface with coarse emery cloth. Now the needle can be magnetised either by rubbing it many times with one pole of a strong horse-shoe magnet, always in the same direction, or by winding a few yards of fairly thick wire (No. 20 or 22 D.C.C.) round it and passing the current from three or four bichromate cells or a four-volt accumulator for a few minutes. At any rate, the needle should be magnetic enough to support its own weight (plus that of the cap) from a piece of iron. It will possibly be found that balance is now upset. This is due to inclination, *i.e.* the N end of a magnetic needle always tends, in our latitude at any rate, to dip downwards. This can be corrected by sticking a stout piece of paper under the S pole with a trace of seccotine. The wooden base and the supports for the wire are made to the dimensions given, and the wire can be of practically any gauge and length (fig. 10). The instrument illustrated is wound with about 8 yards of No. 36 S.C.C. copper wire, and the best results will be obtained by using a fine wire. To wind it neatly, the following plan can be adopted. After the two little supports are made, cut out an odd piece of wood 3 ins. long by ½ in. thick, the width being immaterial. Be careful to see that the ends are at right angles with the other faces, and then, after placing the supports against the ends and holding all firm with the finger and thumb, the wire can be wound round in comfort, keeping it fairly taut. Leave three or four inches at start and finish, and twist the two

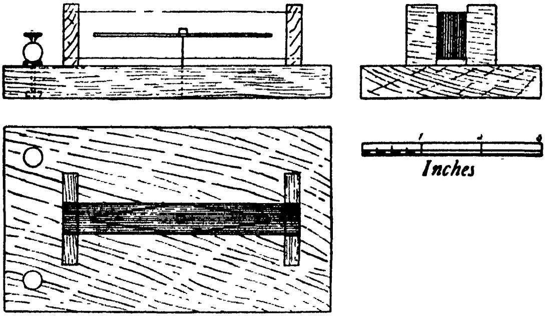


Fig. 10.—Plan and Elevations of Simple Galvanometer.

ends together. Now the little feet can have a spot of glue on each, and the whole arrangement planted down in position on the base. Lay a heavy book or such like on top and leave it overnight to set. The piece of wood which has formed the distance piece can then be carefully withdrawn and the wires led to terminals. The pivot for the needle is a piece of fine sewing-needle driven up from below, after having made a fine hole about half-way through the wood. Leave it so long that the needle swings midway between the coils of wire, and snap off the surplus at the bottom.

This little instrument will serve excellently for three purposes. It will show (*a*) the presence of a current, (*b*) the direction in which the current is flowing, and (*c*) will indicate roughly the strength of the current, *i.e.* it will differentiate between a strong and weak current. It has its disadvantages, as the student will soon discover. First, it must always be placed so that the coil of wire lies in the magnetic meridian; second, considerable time is taken up by the excessive swinging of the needle; and third, it is easily influenced by exterior magnetic fields or even draughts.

A Tangent Galvanometer.—This, again, is a very simple piece of apparatus and has been included because it illustrates the principle upon which a good many forms of testing galvanometers and other measuring instruments are constructed, when heavy currents have to be measured without risk of injury to the instrument. A short description of the tangent scale and the reason for its use will not be out of place. Reference to the drawing showing its setting-out in the next section will show that equal measurements along a tangent of a circle produce gradually decreasing divisions on the circumference of the circle. Now this pretty accurately follows the action of the current upon a magnetic needle. The deflections at first are large in proportion to the current flowing, but as the needle moves away from the meridian, the magnitude of the deflection rapidly falls off, so by letting the needle move over a tangent scale we are able to obtain a far more accurate estimation of the varying deflection than if we divided the circle into equal parts.

The needle may be the same as used in the simple type of galvanometer, but it must swing in a plane (horizontal) through the centre of the metal ring. The ring in the instrument illustrated in fig. 11 is of fairly stout brass about 1 in. wide. Copper or even zinc will do, iron (including the so-called "tin") being out of the question. The square wooden pillar supporting the needle and scale is simply rounded at the lower end and glued into a hole drilled in the base, as in fig. 12. The scale is set out on a piece of stout white card and fastened to the top of the pillar by a couple of brass brads (boot brads are an excellent article for many purposes in our work). Care must be taken that the zero line lies under the centre line of the ring, and of course the needle must take the same position when the instrument is in use. The screws used to fasten the metal ring to the pillar must not touch each other, and this can be secured by putting them off the centre. It will be seen that a current applied passes once only round the needle and at some considerable distance from it. The metal conductor being of good substance offers little resistance, and will therefore stand large currents passing through it, where a fine wire would probably fuse.

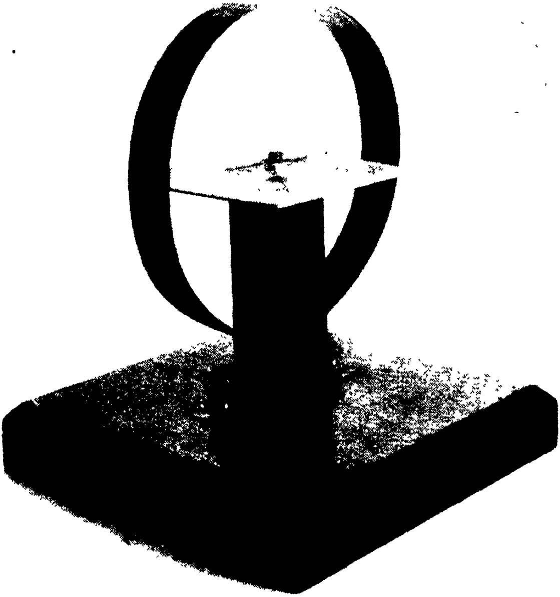


Fig. 11.—Tangent Galvanometer. (⅛.)

Should the student desire to make the tangent galvanometer as close to the regulation form as possible, he should reduce the length of the magnetic needle to about one inch, or even a little less, and attach to it, at right angles to its length, a long, thin, aluminium pointer in the same way as shown for the graded voltmeter in Chapter VIII. If he adopts this plan it will be necessary to alter

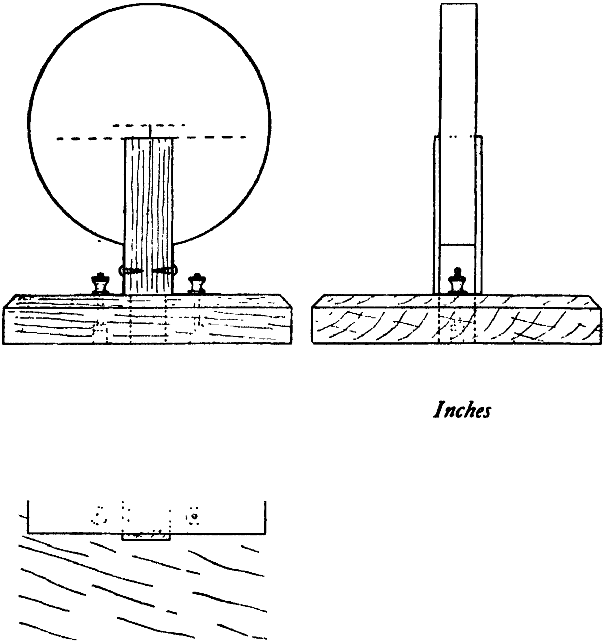


Fig. 12.—Plan and Elevations of Tangent Galvanometer.

the position of the scale card so that the zero line is at right angles to the plane of the metal ring. It could also be larger than that shown—in fact, just large enough to reach across the ring,—and the aluminium pointer made sufficiently long to suit.

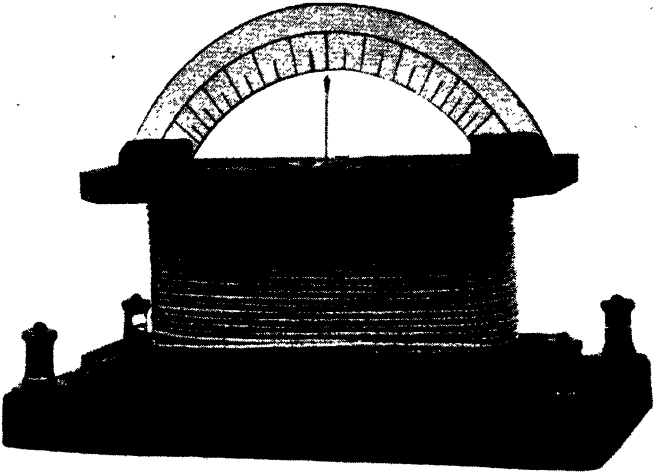


FIG. 13.—A Sensitive Galvanometer. (½.)

A Sensitive Galvanometer.—This instrument presents no great difficulties in construction, and will be found to be really very sensitive and of much general utility. It presents several advantages over the last two types. It has a much greater range of sensibility, is not affected by earth's magnetism, and is much more free from the prolonged swinging of the needle. It is, moreover, fairly robust, and, having a double-sided scale, can be seen by several experimenters when working together. It is shown in figs. 13 and 15.

The sketch, fig. 14, gives a clear idea of the woodwork required, and any well-seasoned wood can be used. That used in the instrument illustrated was turned out from some odd pieces of mahogany the writer had by him. The pieces separating the top and bottom of the bobbin are simply glued into place. Any finish can be adopted as the maker may fancy, a good rubbing with linseed oil serving

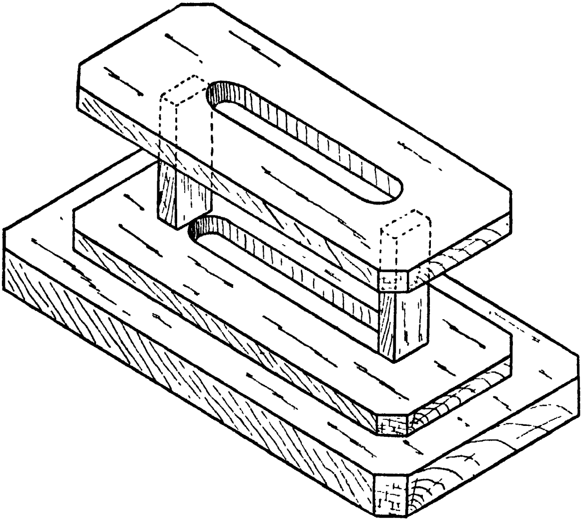


Fig. 14.—Isometric Sketch of Woodwork for Sensitive Galvanometer.

well and preserving from damp. When the glue is

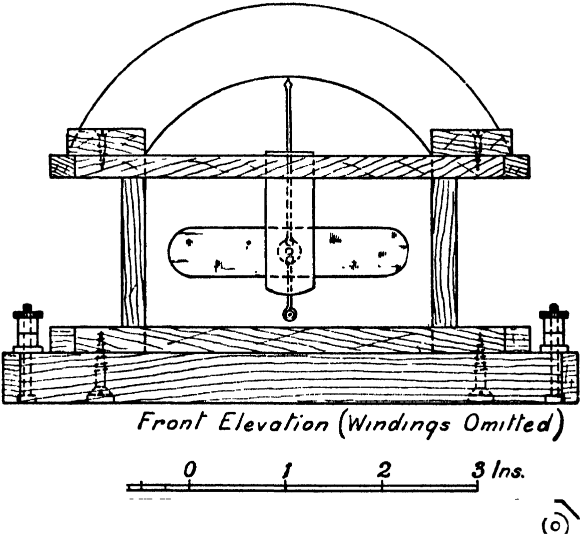
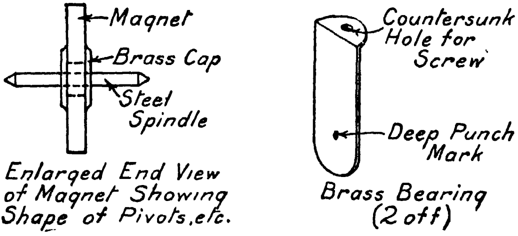


FIG. 15.—Plan and Elevation of Sensitive Galvanometer.

set, cut a strip of thin, strong, brown paper 2 inches wide and about 20 inches long. Slightly damp it and then wind it round the two distance pieces and between the flanges of the bobbin, snipping the corners and securing the commencing and finishing ends with a touch of glue. When all is dry, the paper will have stretched quite tight and will form a good foundation on which to wind the wire, besides strengthening the woodwork. There are two windings of wire. The first is a high resistance winding of two even, close layers of No. 36 (or a gauge somewhere near that) D.C.C. The beginning and finishing ends are led through two small holes at one end of the lower flange. This winding is then given a coat of shellac varnish, and a strip of paper is laid over it and also varnished. The outer winding is two close layers of No. 20 D.C.C., also varnished, and forms the low resistance. The ends of this layer are led through holes at the other end of the lower flange. A final layer of varnished paper could be put over all if desired. The magnet is made from a strip of steel as in the former instruments, but is kept with parallel sides, as we want as large a magnet as possible, and there will not be any need for accurate balancing in this case. Instead of a cap a brass boss is formed in the centre hole, this being done by cutting off the large end of the brass rod quite close to the steel. The spindle is made from a piece of knitting-needle which is just a shade too large to pass through the small hole in the brass boss. If the reader finds the steel needle a little too hard to work, he may use as a substitute a small round wire nail, which is quite soft (fig. 16 (*a*)). It will not, of course, be quite such a good job, but will answer very well. The ends must be worked up to nice points, which must be quite central and finished very smooth. Those with a lathe will make no trouble of this, and those without will find a good method is to put the spindle in the chuck of a small hand-drill. This can be held in the vice and turned with the left hand, while a smooth file is rubbed along the rotating end with the right. When finished, its overall length should just exceed ½ in. Now it may be driven into the hole in the brass boss. This is best accomplished by holding one end of the spindle firmly in the vice and then driving the needle on by using a hollow punch or a little block of metal with a small hole in it. The spindle should project equally on either side of the needle. Magnetising, which ought to be left till this stage, can now be done. The pointer and counterpoise can next be attached. They are made


Magnet
Brass Cap
Steel Spindle
Enlarged End View of Magnet Showing Shape of Pivots, etc.
Countersunk Hole for Screw
Deep Punch Mark
Brass Bearing (2 off)

(*a*) (*b*)

FIG. 16.—Details of Sensitive Galvanometer.

from a bit of the No. 20 wire that was used for the outer winding, of course with the covering removed. They are fastened to the boss with just a trace of solder, a warning being necessary here. Do not make the soldering too long a job or the heat of the iron will injure the magnet. For this reason the magnetisation might be left till later, though it is not then so conveniently done. The lower end of the counterpoise is formed of a small loop of the wire filled with a small blob of solder. By holding the ends of the spindle between the finger and thumb, a little manipulation of the counterpoise will cause the needle to come to rest horizontally with the pointer upright. The bearings are very simple (fig. 16 (*b*)). Two strips of brass (hard for preference), ½ in. wide, are shaped as shown in the sketch, and sockets for the ends of the spindle formed by deep dents made with a centre punch while the brass is resting on the end grain of a piece of hard wood. The bearings should be screwed in place with ¼-in. No. 2 screws, and the magnet carefully lowered into its place so that the ends of the pivot rest in the centre-punch marks. Adjust the spring of the bearings so that the magnet can swing freely, but with no chance of slipping out of place.

The scale, fig. 17, is drawn on a piece of stout, white card exactly as shown in the drawing, taking care that each side coincides with the other. This can be ensured by letting the compass point pierce the card and then continuing the centre line to the edge. This will give the centre line for the reverse side. The measurements along the top line (the tangent) may be anything the maker chooses, provided they are all equal. Those in the drawing are ¼ inches. The scale is now cut out. Use a sharp knife, resting the card on a piece of zinc, and do not try to cut too deep at once. Several light cuts are better than one or two heavy ones. The ends of the scale can be glued to two little blocks

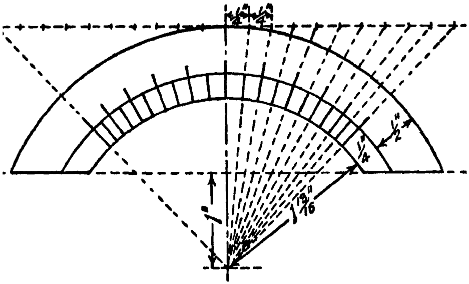


FIG. 17.—Tangent Scale for Sensitive Galvanometer.

of wood which are screwed in place on the top flange. The whole can now be fitted on the base, having drilled holes in it for the passage of the wires and terminals. Channels should also be cut in the under surface of the base for the wires to lie in. It might be mentioned that brass screws should be used throughout, as iron ones might have some effect on the magnet. The high resistance should be in circuit when feeble currents are being used, and the low when more powerful ones are required. As an example of the sensibility of the instrument, it was found that one cell from an exhausted pocket-lamp refill caused the pointer to swing to its furthest limit when connected to the high-resistance coil.

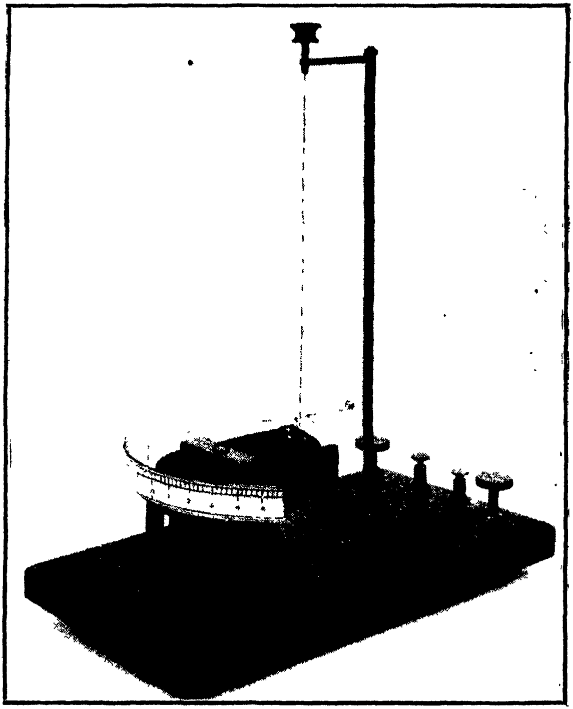


FIG. 18.—Moving-coil Galvanometer (front view). (¼.)

A Moving-coil Galvanometer.—The instrument to be described will require a little more skill and care than the previous examples, but there is nothing really difficult in its construction. As shown in figs. 18 and 19 the actual expenditure amounted to about a shilling.

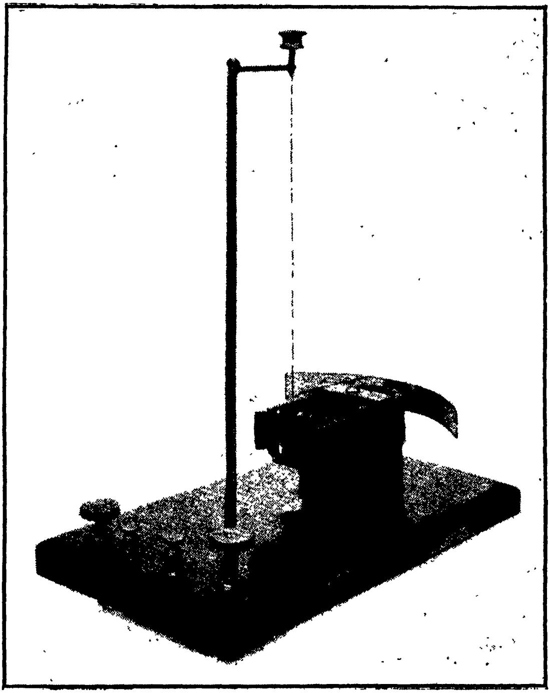


FIG. 19.—Moving-coil Galvanometer (back view). (½.)

A moving-coil galvanometer is generally looked upon as one of the highest forms of electrical apparatus, and it possesses many points of more than usual interest and instruction to the beginner. It will be well, therefore, if we commence with just a short outline of its principles.

In ordinary galvanometers such as have been described, the essential parts are a magnet moving within a coil of wire. The present form is just the opposite, for here we have a coil of wire moving within a permanent magnetic field. The magnet in an ordinary galvanometer must, for reason of weight, be kept within fairly small limits, so that its magnetic intensity can never be very great. In the moving-coil type, however, as the magnet itself is stationary, it can be made very large and consequently very powerful. But now comes another difficulty. In order to preserve the necessary delicacy of action, the coil of wire must be kept of small dimensions, and matters must be so arranged that we get sufficient turns of wire, keep the weight small, and allow for movement, while keeping good electrical continuity throughout. In order to meet these requirements a wire of extremely small gauge is used, and this must be wound on a former to support it. The student will learn later that this former plays an important part in the action of the instrument besides its mechanical duty as support. Usually the former is provided with fine pivots which work in jewels, and current is brought to and taken from the coil by fine non-magnetic hair springs, which also serve to return the coil to its normal position after it has moved. The action is of great instructional value to a beginner, as

Ampère's law is proved, and the principle of an electro-motor is also demonstrated; the instrument being in fact an electro-motor having a permanent magnetic field and a one-coil armature with no commutator. Another advantage it possesses over the ordinary type of galvanometer is that it is almost "dead-beat," *i.e.* the pointer moves across the scale and stops practically dead when indicating the value of the current passing, instead of vibrating backwards and forwards until a position of rest is attained.

To proceed with the construction: the first necessity is the permanent magnet. An ordinary horseshoe pattern would do, except that the space between the poles is usually very limited, and the steel is bent on the flat instead of edgewise. There is, however, a small electric motor sold by several dealers which contains just the sort of magnet we require. It has parallel poles bent edgewise, and as the complete motor costs only 10d., it is well worth the outlay. If you get the chance, test its strength before you purchase. If good, it should be able to support its own weight easily. It must be mounted on a small wooden block, as shown in the illustrations, figs. 20 and 21, this block serving as a support for the core and scale as well. The core is a small piece of cast-iron and serves to concentrate the magnetic lines of force between the poles of the magnet. That in the instrument illustrated was cut from the pillar supporting the gong in an old electric bell. It must be drilled radially and the hole tapped out $\frac{1}{8}$ in. Whit. A small piece of brass wire, $\frac{1}{8}$ in. diam., is screwed to fit, the other

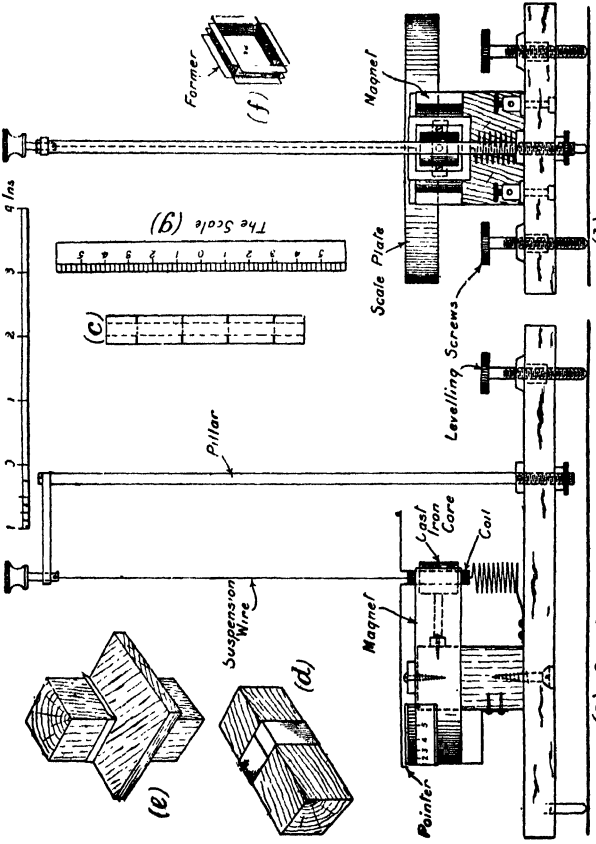


FIG. 20.—Views showing the Construction of a Moving-coil Galvanometer.

end being screwed or soldered into a small brass plate having two countersunk holes by which it is fastened to the block. The magnet itself should have a coat of enamel, and can then be placed in position on its block and clamped down by a strip of brass, which itself is screwed down to the block by a round-headed brass screw. Now to turn to the coil. The former first demands our attention. It must be made of very thin metal. Stiff foil is best, and any metal, excepting iron, may be used. The one illustrated is of copper. The writer tried aluminium for the sake of lightness, but as this metal cannot be soldered, there is some difficulty in making a practical joint. The strip of foil must be free from buckles, and after cleaning up should be marked out as shown in fig. 20 (*c*), the heavier lines representing cuts. Now plane up a piece of wood, hard for preference, exactly $\frac{3}{4}$ in. square, and carefully bend the strip round it, keeping the angles nice and sharp. Next solder the lap, using as little solder as you can, a mere film being sufficient (fig. 20 (*d*)). Now prepare another piece of hard wood, $\frac{3}{16}$ in. thick, and cut out from it a piece forming an exact right angle, the sides forming the right angle being $\frac{3}{4}$ in. Now, with the help of a friend or the vice, by placing this piece of wood in position and holding it there firmly the edges of the foil can be bent over one at a time, using a smooth piece of metal to get everything nice and flat (fig. 20 (*e*)). The former is now complete and should appear as in fig. 20 (*f*). Keeping it on its mandrel it can now be wound. For this purpose a single-covered copper wire of as fine a gauge as possible must be used. The one described is wound with No. 42 S.S.C., which was saved from a broken portion of some scrapped electrical apparatus. At any rate, it is easily obtained, and the small quantity required will cost very little. A friendly dealer would probably make a pennyworth. The layers must be kept as close and even as possible, and the insulation must be carefully guarded. The writer managed to get on about 30 yards. When full, bind round the commencing and finishing ends with silk thread so that the ends are situated at the centres of two opposite sides, leaving about 8 inches free, and then give it a soaking with *thin* shellac varnish. The pointer now requires placing in position. It is formed from a thin piece of copper or brass wire bent to shape and size as shown, the right-angled end being flattened, shaped, and touched with black enamel. It could be soldered to the former with a stirrup-shaped end to span the thread lashing, which was the plan adopted by the writer; but if you do not care for such a tricky job, lash it on with silk thread, which can be varnished to stiffen it. Projecting in an opposite direction to the pointer we must have a counterpoise, which is also of copper or brass wire, the projecting end being coiled up into a tight little spiral, which can, of course, be cut shorter until right, or it can be left straight and have a tiny leather washer sliding stiffly on it. Whichever plan is adopted, the great point to keep in view must be extreme lightness; so adjust matters that when you let the coil hang from its upper lead the pointer swings horizontally. Of course, it is understood that the width of the former must be such that it can be placed between the poles of the magnet with a little clearance, so that if the magnet you obtain differs in size from that illustrated, the measurements of the former must be altered to suit.

We have now to devise some means of suspending the coil so that it may turn freely on a vertical axis. As before mentioned, the commercially made instrument generally has its coil mounted on pivots, although in some makes it is suspended; and that is the method here adopted. A pillar must therefore be prepared. The one illustrated is of $\frac{3}{16}$-in. brass rod. Brass strip would do, but would not be so rigid. It should be provided with a projecting arm at the top, either screwed or soldered on, and some means of fastening it rigidly to the baseboard, either as shown or by a small plate soldered on, the plate being screwed down. Measurements can be obtained by reference to the drawings. At the outer end of the projecting arm is fitted a small peg with a milled head. A portion of an old terminal does very well. This peg should slide stiffly in its hole, this being managed by slitting the brass with a fine saw and pinching the outer ends together. Its purpose will be indicated later. Between the legs of the magnet and fastened to the baseboard is a thin springy piece of brass shaped as shown. Now the lower wire from the coil should be wound in a large spiral and its end carefully soldered to the end of the brass strip just mentioned. The upper wire must be kept straight and soldered to the peg in the projecting arm at the top of the pillar. The length of this wire should be just sufficient to allow the coil to hang centrally between the poles of the magnet; so that now we have the coil in such a position that it is able to turn round within the space between the magnet poles and the iron core and yet not touch either. A wire from the pillar base and another from the brass strip on the baseboard can now be led to a pair of terminals, as in fig. 21. There now remains the scale. This, as will be seen, is attached to the magnet block on the opposite side to the core support. A piece of zinc is cut to the dimensions shown and then bent to the correct arc. A narrow strip of brass is then soldered on centrally, and by this it is fastened to the block. The marking out should be done first and the paper can then be stuck on the zinc with seccotine, first roughening the metal with coarse emery cloth. The divisions on the scale can be to the fancy of the maker. In the present case each large division is 1 cm. divided into five parts, zero being at centre, as shown in fig. 20 (*g*). It may be that the pointer does not rest at zero. A gentle twisting motion to the peg at the top of the pillar will soon put matters right, and in the event of it being necessary to carry the instrument about, the peg may be pushed down, allowing the coil to rest on the core, thus avoiding breakage of the suspension. It will be noticed that the baseboard is provided with levelling screws, and this will be found necessary. Those illustrated were previously made but not used, so they came in nicely. Quite efficient ones can be made by soldering a strip of brass into the slots of ordinary wood screws 1½ ins. long (No. 4 or 5). If they are made to move freely in their holes, they are quite as effective as more elaborate ones. The baseboard and wooden block can, of course, be finished to the fancy of the maker.

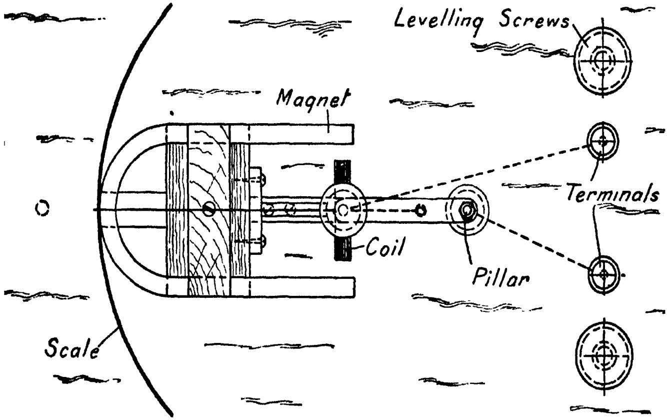


FIG. 21.—Plan of Moving-coil Galvanometer, showing Connections.

One remark is probably necessary. Very few measurements have been given. This is because such a great deal depends upon the size of the magnet, and because a great deal of latitude can be allowed as the various parts can be constructed from odds and ends, though if reasonable care is exercised no great difference will be made in results. A little fitment the author has added, but not illustrated is a small piece of cast iron—part of an old electric bell frame—which is placed across the magnet-poles and core when the instrument is not in use. This tends to preserve the strength of the magnet.

The instrument is now complete and may be tested. It must be remembered that the instrument is extremely sensitive and must be used for very tiny currents only. Anything like a strong current would produce very violent movement of the coil with almost certain damage, or it might even burn out. A method of testing may be conducted as follows:—To one of two fairly long leads of thin copper wire, which are fastened to the terminals, attach a small piece of zinc. On this zinc plate a small scrap of flannel, moistened with salt water, is placed. If the instrument is now levelled and the pointer brought to zero, the piece of flannel may be touched with the bare end of the other lead. If all is correct, the pointer should swing over three or four divisions. When in use for testing purposes, etc., a high resistance must always be in series with the instrument. And this brings us to our next consideration, viz., *resistance*. The student will have come across this term many times, and will doubtless know that all substances tend to obstruct the passage of current through them. This obstruction is better termed "resistance," and is shown only feebly in some substances, these being generally known as conductors, while those which offer great resistance are often called insulators. He will see, then, that we are able in some measure to regulate the flow of current by placing resistance in its way. A 200- or 220-volt lamp will form a high resistance, for instance. Old lamps can generally be had for the asking, and, provided the filament is intact, will serve well as a resistance. A 200-volt 16-c.p. lamp has a resistance of roughly 500 ohms, and it will be a very interesting study presently for the beginner to obtain a variety of lamps and work out their resistances. The comparison between carbon and metallic filament lamps as regards light given and current consumed could be undertaken, using small battery lamps. The use of a lamp as a resistance permits but one fixed resistance, and the amateur would probably prefer an arrangement where he could adjust matters to suit various conditions. Such a piece of apparatus is generally termed a "rheostat," and the one described will prove a useful adjunct to the student's list of instruments.

A Rheostat.—This consists of a piece of broomstick, 8 or 9 ins. long, mounted immovably between two wooden uprights (fig. 22). On it is wound a close layer of some resistance wire which can easily be obtained and will not cost much. That in the

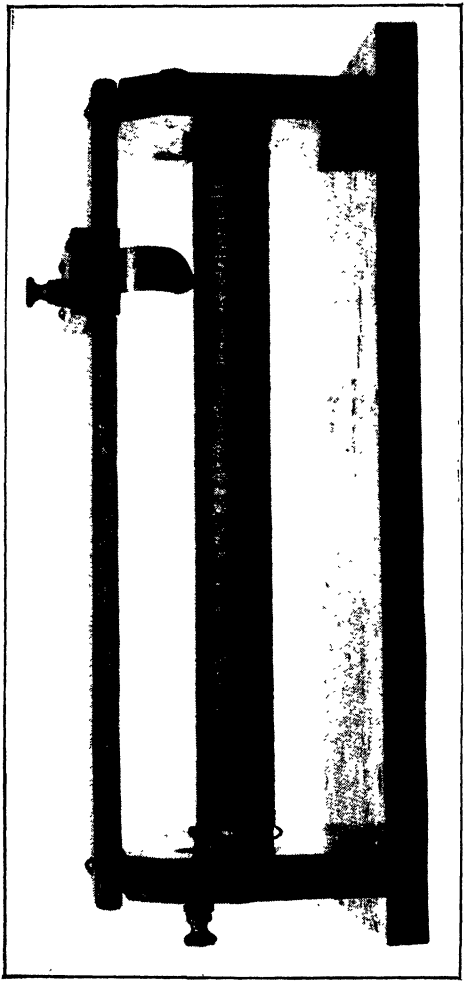


FIG. 22.—A Rheostat. (¼.)

NAWAB SALAR JUNG BAHADUR

example shown is No. 23 S.S.C. "platinoid," about 25 yds. being used. Each end is fastened to a terminal on one of the uprights, although one end might be twisted round a small brad to prevent it unwinding. The former method will allow of the rheostat being used as a potentiometer in the same manner as will be described later. The maker must be guided as to the particular gauge of wire, according to the current (amperage) it will be required to carry safely. The gauge mentioned was used because a quantity was at hand, and will carry 1 amp. without overheating. If a larger gauge is used, the length of the wooded mandrel might be increased in order to accommodate sufficient turns to give a long range of adjustment. When wound and secured, the whole, wood and wire, is given a good coat of varnish. Fixed to the slider which travels along the wooden bar attached to the supports is a springy brass finger which presses on the wire. Along the track this finger makes, the insulation and varnish are scraped off the wire so that the two make good contact. A terminal is also fixed to the finger. It will be seen, then, that if the slider is at either end, hardly any of the resistance wire is in circuit, but as it is moved to the other, so more and more is included till at last the maximum is in use. This provides us with a means of regulating very gradually the resistance we desire to place in series with the cells and whatever apparatus we may be using. It should be mentioned that to make a satisfactory job, the

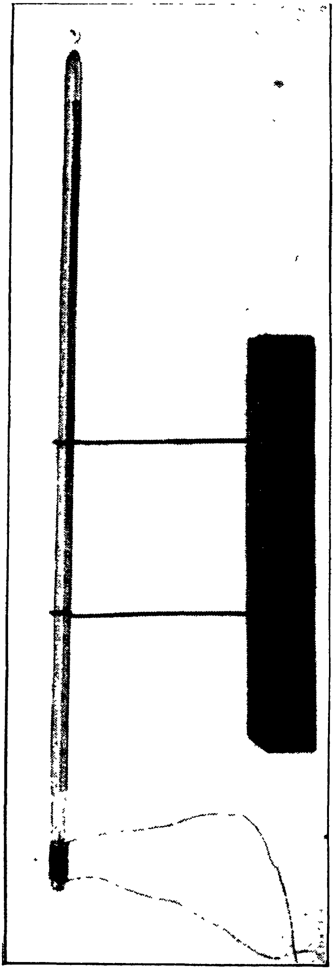


Fig. 23.—Thermometer with Coil of Resistance Wire for showing Heating Effects. ($\frac{1}{3}$.)

bar carrying the slider should be of oak or some other stiff wood.

Thermal Effects.—The student will quickly find that the wire of his rheostat becomes warm when in use, and will probably have learned that the passage of a current along any conductor is always accompanied by heat, this being the outcome of resistance. Generally the heating is so slight as to pass unnoticed; indeed, heat being a waste of energy from the electrician's point of view, he takes care to make his conductors of such size that the resistance may be as low as possible. Sometimes heating is deliberately aimed at, and this is, of course, why an electric lamp "lights up." It is not easy for the amateur to construct any apparatus of utility on this principle; certainly not to make lamps for himself. He could, however, wind a yard or two of fine resistance wire, the finer the better, round the bulb of a thermometer and so actually measure the heat developed by a certain current. One of those with a paper scale inside a tube, such as is used for testing the heat of a bath water, for instance, is the best form, unless he has a sensitive thermometer such as is used in scientific work (fig. 23). Support it in some method, note the temperature, and allow the current to pass for a definite time. A rise in temperature will be observed, and it is easy to imagine some sort of meter could be worked out on these lines. There are, however, many difficulties in the way, which we shall not consider, which prevent this being successfully carried out.

CHAPTER V

ELECTRO-MAGNETISM

THE student will know by this time that magnetic effects are produced by a current passing through a conductor, that this effect is far more noticeable if the conductor be formed into a coil or helix, and also that it increases with the number of times the current circulates. The galvanometer, for instance, depends for its action upon this fact. But the magnetic field so produced, besides affecting a magnetic needle, behaves towards ordinary non-magnetic iron or steel in a similar manner to a permanent steel magnet. By the term "non-magnetic iron or steel," the author means iron or steel which exhibits no magnetic polarity; because it is now generally accepted that all iron and steel is magnetic even though it does not produce an exterior field. In order to demonstrate this a little more fully, a simple piece of apparatus is described, which, although not of great utility, is an example of the principle upon which a good many forms of apparatus are based.

A Solenoid with Spring Armature.—A hollow coil of wire containing no iron "core" or centre is termed a solenoid. Make a small paper tube by winding tightly and evenly round a lead pencil a strip of thin tough paper. The strip might be 2 ins. wide and 12 ins. long. One side of it is glued after the whole has been well damped. If wound round and kept taut all the time, the glued side being outwards, this will form, when dry, a very stiff, strong tube having an internal diameter of about $\frac{5}{16}$ in. Now prepare two wooden discs or flanges about $1\frac{1}{8}$ ins. diam., having a central hole just large enough for the paper tube to fit tightly Wooden discs are of great service for making bobbins, and an excellent material for making them will be found in thin three-ply wood $\frac{1}{8}$ in. thick. This can be obtained in large sheets of various thicknesses, but packing-cases, especially tea-chests, are often made of it, and the purchase of one will provide a lot of material at less cost than a sheet. Glue these discs on, one at either end, and you will have a nice strong bobbin. Make a tiny hole in one flange quite close to the tube, and after threading an end through this hole wind the space full of wire; No. 24 will do, and this is quite a common size of wire, being largely used for winding electric bell bobbins. Indeed, a wound bobbin, if in good order, from an old electric bell will serve our purpose well; but there may be some difficulty in removing its iron core, as these often become very firmly fixed in time. Mount the completed bobbin on a baseboard and rig up a framework over it, as shown in fig. 24. Now make an iron core which will slide freely in the tube. A piece of stout, round wire nail will do excellently. Drill a small hole at

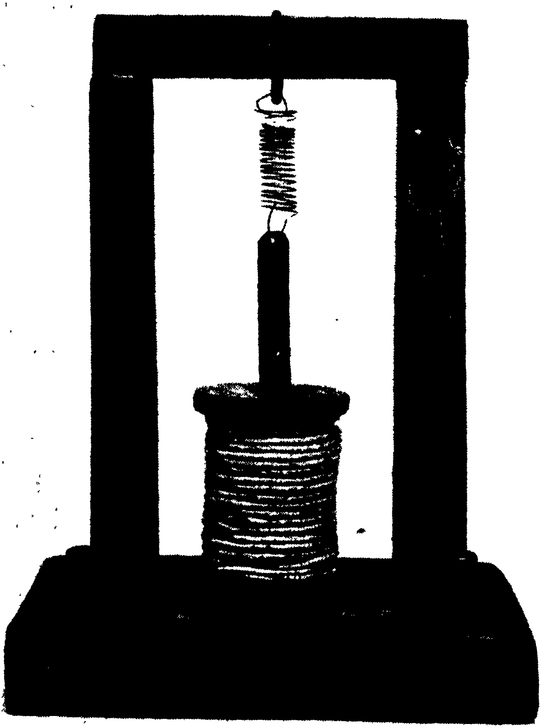


FIG. 24.—Solenoid with Spring Armature. (§.)

one end, and support it from the cross member of the framework by means of a weak spiral spring so that its lower end just enters the tube. The spring must not be strong by any means, and one can easily be made by coiling up a length of steel wire such as is used in making Bowden brake cables, or a mandoline E wire will serve. Now, if a pair of bichromate cells be made to pass current through the solenoid, the iron core will be sucked into the tube—the stronger the current the greater and more violent the movement. The student will see that it would be fairly easy to construct a scale, over which a pointer attached to the upper end of the core could move, which could be marked showing the various strengths of current required to produce certain movements of the core. As a matter of fact, meters are made on this principle. The same sucking action of a solenoid often forms the source of movement in other forms of apparatus; and the reader may have seen small motors constructed where this idea is used, the action appearing similar to that of a steam-engine piston, though there, of course, it is a pushing action owing to expansion.

Electro-magnets.—It will be readily understood that if we fill up the hollow centre of a solenoid with an iron core we have an electro-magnet. These can be of any size or shape, practically speaking, and are used in one form or another in a great variety of electric apparatus. The student is advised to spend some little time on experimenting on them. Variations in size of core, both as regards length and thickness, number of turns and gauge of wire, electrical energy supplied, position of winding on the iron, etc., provide a very wide field for research. As some indication of how to proceed, instructions are given for making two very simple forms: the first a bar, and the second a horseshoe pattern.

(a) *Bar Magnet* (fig. 25).—The iron can be of any convenient length and diameter, and need not be round, even. The iron, however, should not be hard, and in any case is best annealed. To do this the simplest plan is to drop the piece into the fire the last thing at night and leave it there till morning. It should then be cleaned up and insulated. This is best done by wrapping round it, tightly, a couple of layers of thin brown paper, giving this a coat of varnish which will serve the double purpose of increasing insulation and fastening down the paper. Now the wire may be wound on. Flanges can be dispensed with, letting each layer of wire be one turn less at either end than the previous one. If flanges are used, they can be

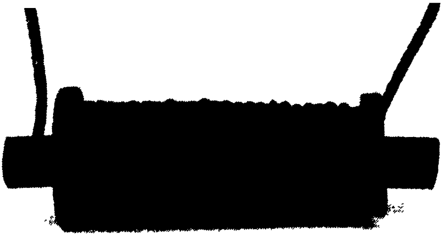


FIG. 25.—Electro-magnet—Bar Form. (¾.)

of three-ply wood as suggested for the solenoid. The centre holes should be a tight fit over the paper wrapping and either glued or varnished on. The whole space can then be filled with wire. That used on the examples illustrated is No. 20 S.C.C.

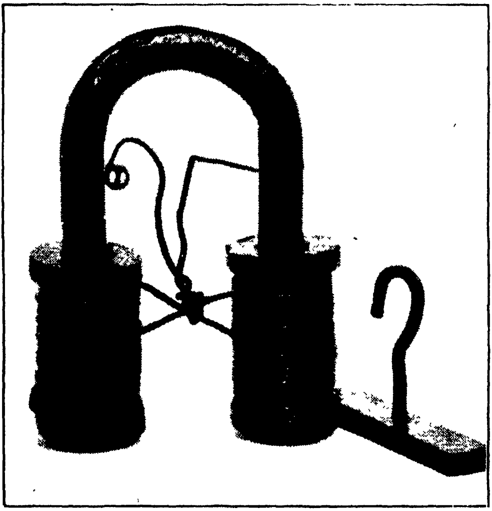


FIG. 26.—Electro-magnet—Horseshoe Form—with Armature. (½.)

(b) *Horseshoe Magnet* (fig. 26).—This form is turned out in a similar manner, care being taken to reverse the winding on the second pole, and also to file the two pole faces perfectly level with each other. Each limb received six layers of No. 20 D.C.C., and the magnet supported 1 kgm. (2·2 lbs.) when energised by two Leclanché cells, although it was rather an unfair task for them.

The forms and uses of electro-magnets being so varied, one or two applications are given which will prove of value both from an instructional as well as a practical point.

The Electric Bell.—Most amateurs are acquainted with the working parts of this article, and if they do not already know details of its action they should make themselves familiar with it by tracing out connections and examining each part closely. It may seem hardly worth while constructing a bell, as they are so common and can be obtained so cheaply, but it will form a splendid exercise if the amateur feels so inclined. Just a few hints are therefore given. The regulation bobbins fitted to a cast-iron frame could well be replaced by a miniature horseshoe magnet wound with No. 24 S.S.C. wire. The armature could be a strip of hoop-iron or a rather thicker piece of cast iron if that is available. The armature spring could be a short length of *thin* clock spring riveted to the armature and also to a right-angled piece of brass or iron which would act as a support. The hammer could be a small nut soldered to a stiff piece of iron wire which is also riveted to the free end of the armature. The contact spring is best made of a thin piece of springy brass and, properly, should be fitted with a platinum contact, although silver answers just as well in this case. A simple method of making the contact is to obtain a little scrap of silver from some broken piece of jewellery and solder it on to the lower end of the brass strip,

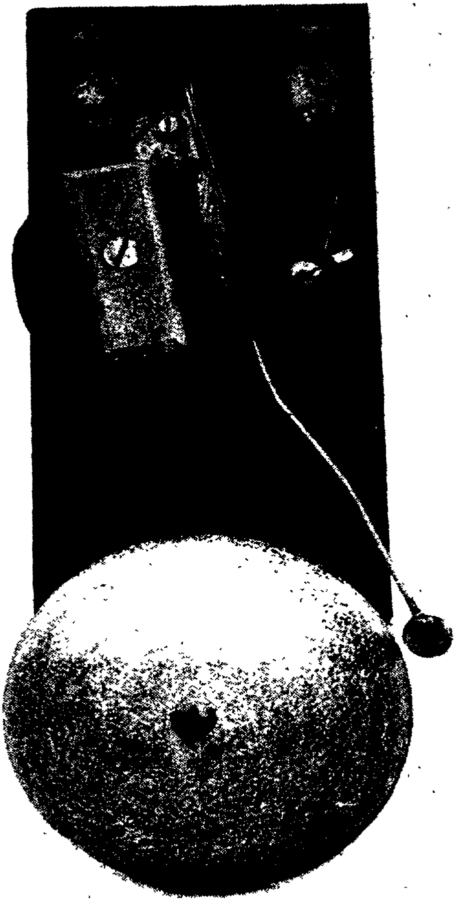


FIG. 27.—Electric Bell. (½.)

the upper end being riveted to the armature at the same time and with the same rivets as are used for the supporting spring. Alternatively, the two springs could both be made in one—that is, the broad clock spring forming the armature spring could be tapered almost to a point and bent outwards from the rivets. This method answers very well and saves some fitting. The contact screw can no doubt be found in the scrap-box, and would be already tipped—probably with silver. If not available, then a little screw fitting tightly into a small brass support can be fitted, having its free end tipped in a similar manner to the contact spring. Connections are as follows: one end of magnet winding to a terminal, the other to the armature spring; and lastly, a wire from the contact screw to the second terminal. A bell made on these lines is illustrated in fig. 27 for the would-be maker's guidance.

An Indicator.—This is another well-known and much-used adaptation of an electro-magnet. There are several forms in use, but the simplest is known as the "pendulum." It consists of an electro-magnet, which is connected in series with the bell, and a light suspended armature which carries on an extension a flag bearing a number or other device, as in fig. 28. When current passes in the bell circuit the armature is drawn up to the magnet, this pulling the flag away from the vertical position. On current ceasing, the magnet, no longer being attractive, looses the armature which then swings backward and forward for a minute or so. Such an indicator is illustrated, and it will be seen from fig. 29 that the framework is formed from one strip of iron. Stout tin would do, but a thin piece of hoop-iron or such-like is better. The magnet core is made from a length of stout wire nail, one end being shouldered down and riveted to the frame, while the other is bevelled to the same angle as the armature will make when attracted. The armature itself is a small piece of tin, and so is the flag, the two being joined by a piece of thin brass wire soldered on. The suspension at the top is also of brass wire. Several of these movements could be

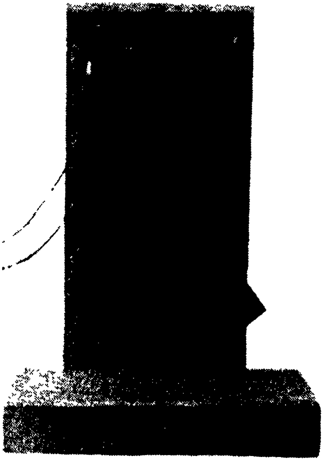


FIG. 28.—Pendulum Indicator. (½.)

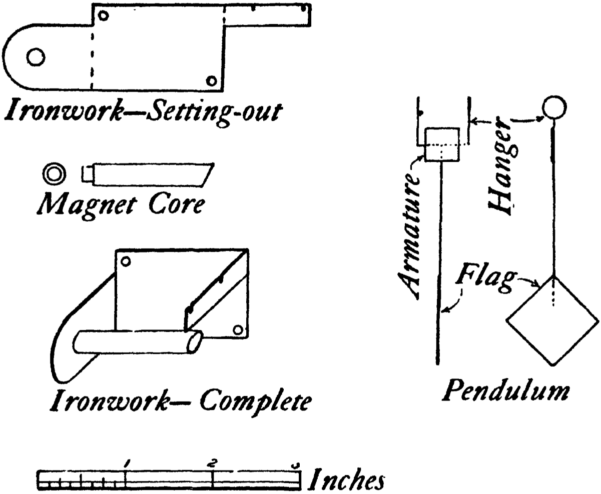


FIG. 29.—Details of Pendulum Indicator.

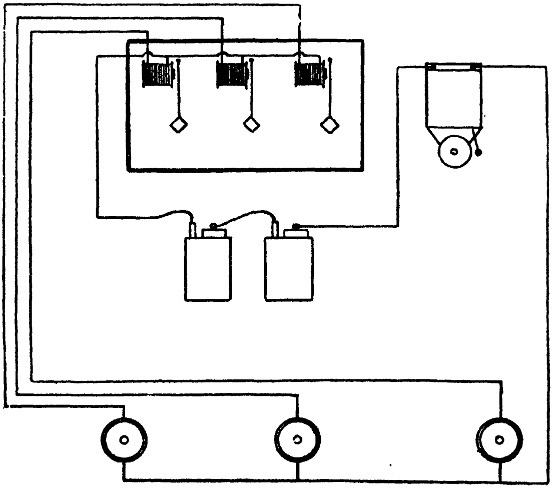


FIG. 30.—Connections for Bell and Indicators.

made and fitted into a neat case with a glass front in the regulation style. A diagram is given in fig. 30 showing the method of wiring.

A Morse Sounder and Key.—This is another well-known and extensively used adaptation of the electro-magnet. It is usually a prime favourite with beginners, as its use provides plenty of instruction and recreation. Incidentally, too, its construction will prove a valuable exercise in simple apparatus making. If any of my younger readers are Scouts, they might find a set of these instruments a useful addition to their equipment. The key, although more of a mechanical than an electrical fitting, is an indispensable item of the set.

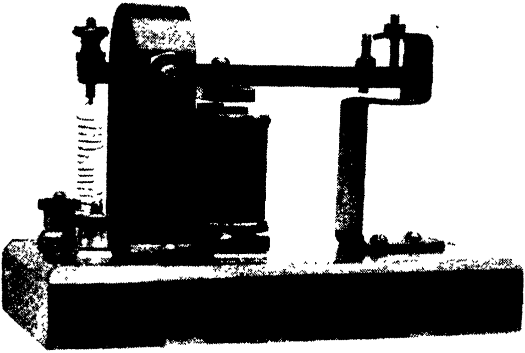


FIG. 31.—Morse Sounder. (⅗.)

The Sounder (fig. 31).—The chief feature here is the pair of bobbins; and it may be that the measurements given will require modifying in some cases, as they formed the basis upon which the whole instrument was built. They were taken from an old, discarded electric bell, and the first operation was to saw off all the portions of the framework except the yokeplate. This then had a couple of holes drilled in convenient places to take round-headed screws by which it was fastened to the baseboard. Care must be taken not to break off the projecting wires, or there may be some trouble in fitting new ones. The original armature can have its spring and hammer wire removed and then be riveted to the rocking-bar. Previous to this it would be well, perhaps, to do all the drilling, etc., required to this bar, which is of $\frac{1}{4}$ in. square bright mild steel. A good substitute for this material is the square spindle which joins the handles of an ordinary door lock. At one end a $\frac{5}{32}$-in. hole is drilled, and $\frac{1}{2}$ in. from the other end a $\frac{3}{32}$-in., this one being tapped $\frac{1}{8}$ in. Whit. To make the pivot, drill a $\frac{3}{32}$-in. hole in about the position shown, only at right angles to the others, and then find a round wire nail which is just a shade too large to enter the hole. After very carefully filing, slightly taper; this must be driven in tightly so that about $\frac{3}{8}$ in. projects. Now the ends can be cut off exact to $\frac{3}{8}$ in. and nicely filed to points which must be central. Smooth them up and bring to a polish if possible. The writer prefers to make these pivots in a slightly different way. The nail is cut to the right length and then pointed, by filing, either in the lathe or while held in a hand-drill, the drill itself being held in the vice. Better points can be formed, and the finished pivot is then held in the vice and the bar driven on to it, using a hollow punch or a thick piece of metal with a small hole in it. The pointed ends of the pivot will work in holes in the ends of grub screws passing through the bearing frame. With a little care this proves a most excellent fitting, being quite free but beautifully steady. The bearing frame is made of mild steel strip about $\frac{3}{4}$ in. wide and No. 16 gauge, although a stiff piece of hoop-iron will serve well. Bend it up to the proportions shown in fig. 32, and then, by placing the bobbins and rocker bar temporarily in position, the centres for the grub screws can be marked about $\frac{1}{8}$ in. above the pivot centres. Next drill holes right through both sides, keeping them exactly opposite each other, and tap $\frac{3}{16}$ in. Now make two grub screws by screwing a piece of $\frac{3}{16}$-in. iron rod and cutting off two $\frac{1}{2}$-in. lengths. Up one end of each drill centrally a $\frac{1}{16}$-in. hole for about $\frac{1}{8}$ in., and across the other ends make a saw cut. The rocker bar can now be placed in position with the pivot ends resting in the holes in the grub screws, when, after adjusting, the locknuts will make all secure. Through the tapped hole in the rocker bar passes a short length of iron wire screwed $\frac{1}{8}$ in. Whit., and fitted with a locknut. Through the $\frac{5}{32}$-in. hole passes another piece of wire also screwed $\frac{1}{8}$ in. but provided with a milled nut, a terminal head doing

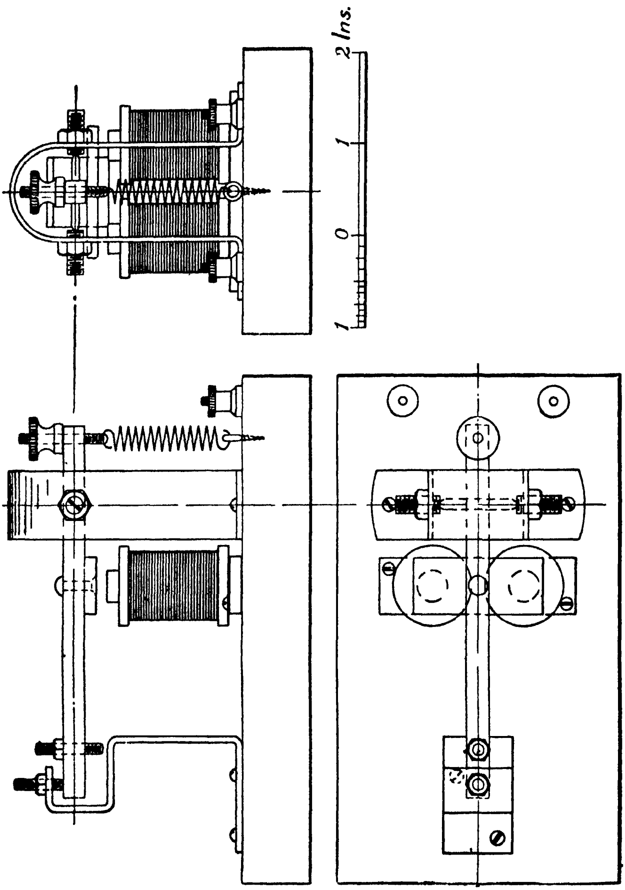


FIG. 32.—Plan and Elevations of Morse Sounder.

splendidly, while a tiny hole drilled at the other end takes the tension spring. This can be made from a length of thin steel wire as in the case of the solenoid. It should be provided with two loops, the lower being fastened to a small screw eye fixed in the base. All that now remains is the anvil. This is made to the shape shown, from a piece of the same mild steel strip as was used for the bearing frame. Through the top projecting arm a hole is drilled and tapped $\frac{1}{8}$ in. Whit. and then provided with an adjustment screw similar to that at the end of the rocker bar. The holes in the foot, for holding-down purposes, should be drilled somewhat diagonally. This will enable the inner one to be screwed in comfortably and will also make a more solid bearing on the baseboard. The whole can now be fitted up, after enamelling the ironwork, to a good solid baseboard. A good thick piece of hardwood is best, as the instrument then gives out a better sound. The one illustrated is mounted on a piece of 1-in. pitch pine. Fit a pair of terminals, and then test with one Leclanché cell, altering the tension spring and the screw on the anvil and rocker bar till a crisp, sharp action is secured.

The key can now be taken in hand, and is very simple. It is shown in figs. 33 and 34. The bar is $\frac{1}{4}$-in. square metal as used for the sounder. It has a hole tapped $\frac{1}{8}$ in. at each end and is provided with pivots in exactly the same way as the sounder. The bearings were made in the same way also, and

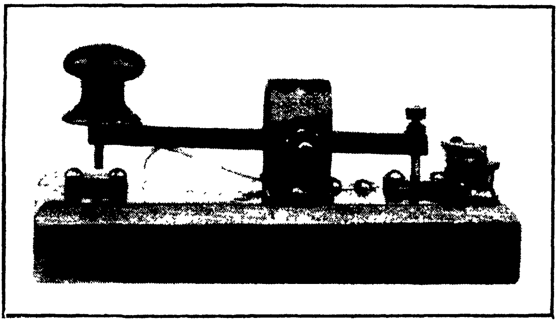


FIG. 33.—Morse Key. (½.)

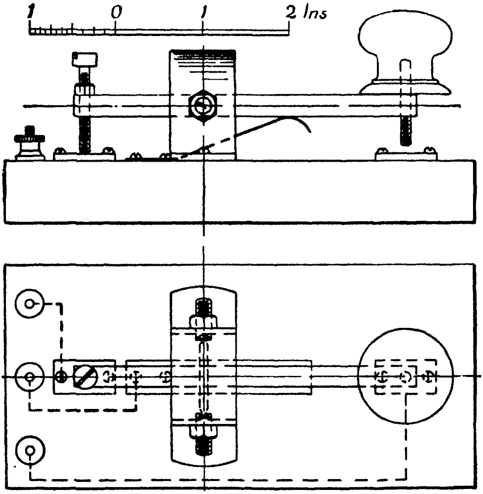


FIG. 34.—Plan and Elevation of Morse Key.

the frame is of the same strip metal. The hole at one end is provided with a brass $\frac{1}{8}$-in. screw carrying a locknut, the screw at the other end being fastened into a small wooden drawer-knob. To do this, drill a hole in it a little too large, fill it with powdered sealing-wax, and after heating one end of the screw drive it in tightly. When the wax has cooled, the screw will be quite firm. The spring in this case is formed from a short length of stout clock spring. This is softened at one end, and has two small holes punched in it. Through these pass two round-headed brass screws which hold it to the baseboard, which should be fairly substantial and hardwood for preference. The contact plates are made from stout brass, and, although perhaps not quite up to the usual specification, will be found to answer well. The important point to notice in connection with the key, is to keep the action very limited, $\frac{1}{16}$ in. being quite sufficient. This can be done by altering the rear contact screw. Make sure, also, to have a piece of really stiff clock spring, or the action may be uncertain. This finishes the instrument making; two of each being needed of course for a complete installation, and tests may be made from one room to another, or from one end of the garden to indoors (fig. 35). For short distances one Leclanché cell at either end will suffice and the "line" can be of ordinary electric bell wire, twin being very convenient. If the two stations are to be some little distance apart, then two cells at either end will be necessary; and if the line is to be more or less permanent, bare wire of about No. 20 gauge can be used, this being supported on insulators. An illustration is given (fig. 36) showing how the line wires were fitted at a school where these instruments were made and are in pretty constant use.

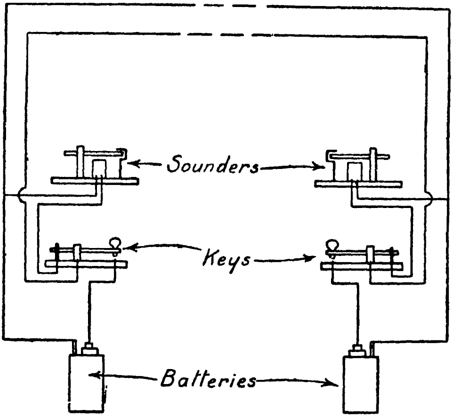


Fig. 35.—Connections for Morse Telegraph Installation.

The insulators here are china drawer-knobs which give every satisfaction. If required for field use, in the case of a Scout Troop, for instance, the line could be a coil (110 yds.) of twin wire coiled up for transport on a large wooden reel, while the cells and instruments could be housed in wooden boxes having a strap handle. It would be imperative in this case for the cells to be of the "dry" type. If the wire also was well served with Stockholm tar or some other preservative in addition to its waxing, there would be little risk in trailing it along damp ground.

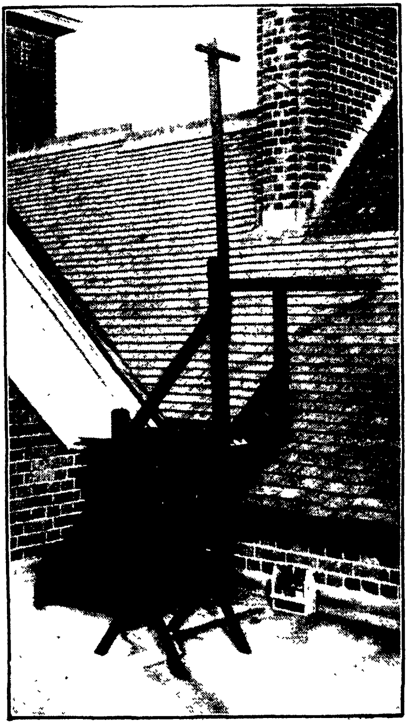


FIG. 36.—A Morse Telegraph Station (showing line, etc.).

Electric Motors.—We shall next proceed to get some idea of how electro-magnets are adapted to produce a continuous movement. At present the magnets we have considered have attracted an armature to them and so produced movement. It is easy to see that it might be possible to make this movement be continually repeated, and each impulse turn a crank and so produce rotation of a spindle. This idea is often carried out in small toy motors, and has even been utilised in quite large ones; but it is, however, an unsatisfactory way of obtaining rotatory action where any degree of power is required. A far better way is to let the armature be continually subjected to attractive impulses and itself revolve. And here we have two courses open; first, the armature may be of iron in the ordinary way, or, second, it may take the form of an electro-magnet and so utilise the far greater reaction which takes place when two magnets are brought together than when only one and a simple iron armature are used. Three types of electric motors, all very easily constructed and quite simple, are illustrated; and they will serve to give the student an insight into the why and wherefore of the larger commercial forms of continuous current motors. They are not intended to be used as sources of energy, although the second form will, if carefully made, develop quite a respectable amount of power considering its size and method of construction, and would no doubt drive such things as the small models of machine tools as sold in toy shops, or even, perhaps, a small vacuum tube rotator or little fan.

An Attraction Motor (fig. 37).—This illustrates the form where the armature is of iron and is attracted by the magnet twice in each revolution of the spindle. The impulses it receives are momentary, however, and continuous rotatory movement is produced by a kind of flywheel action; that is, the energy produced by the attraction of the magnet causes the armature to turn too far, and before its movement dies out it has caused another momentary current to flow through the magnet.

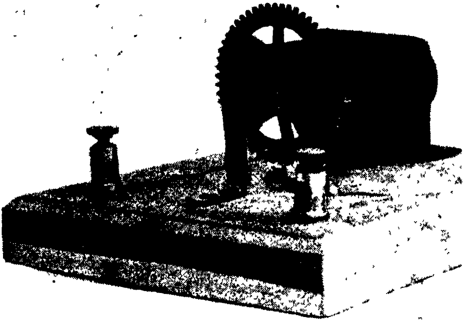


FIG. 37.—Simple Attraction Motor. (½.)

The magnet could be very well adapted from the bobbins of an electric bell, but if home-made they should be of somewhat the same size and construction. The armature is simply a strip of iron long enough to span the poles, and of fair thickness. It is best fastened to a wheel such as a large clock wheel. This provides a spindle and overcomes the difficulty of producing a true wheel if a lathe is not available. If the teeth are objected to, they may be filed off. The iron armature might have a hole drilled at its centre large enough to slip over the spindle and then be riveted to the rim or two opposite arms of the wheel, but care must be taken that the latter is not thrown out of truth. A couple of bearings can be rigged up out of strip brass, and then the whole assembled on a baseboard in such a manner that the centre of the spindle coincides with a centre line through the poles of the magnet. The armature should be allowed about $\frac{1}{16}$ in. clearance from the magnet poles; and it might be mentioned that the bearings should be fairly strong, or the pull of the magnet may bend them and cause the armature to touch it. Now the most important part of all requires fitting. This is the contact-maker. It consists of a small lozenge-shaped piece of brass fixed tightly to the spindle. Its exact position must be found by trial, so it is best to leave the fastening, and a touch of solder is most satisfactory, till a trial run has been made. The following is a pretty near estimate of its position. Suppose the armature to be resting on a clock-face, so that its ends are over XII and VI, then the points of the contact-maker should point to II and VIII. Fastened to the baseboard is a piece of stiff, yet thin, brass, in such a position that when the contact-maker is resting horizontally one of its points should make a good rubbing contact on it. Now connections can be made and a trial run taken. One wire from the magnet goes to a terminal, the other to one of the bearings, and the brass spring is the second terminal. The pressure of the spring will probably need adjusting as well as the position of the contact-maker; but if reasonable care has been taken the motor should develop fair speed with one bichromate cell, though two are better. The motor is not self-starting, so will require a touch to the wheel till the first contact is made. The illustration gives a good idea of the general construction. As a further example, a motor might be constructed on similar lines, only having two armatures so that the four ends make angles of 90° with each other. This form would necessitate a contact-maker having four points, and a square piece of brass would be best. The points of the contact-piece should be about midway between the arms of the armature. This form would probably give more speed, and would certainly be steadier in running.

We now proceed to consider motors having electromagnetic "fields," as they are termed, and also electromagnetic armatures, these latter necessitating a "commutator," which is a device for changing the direction of the current, in order that each section of the armature may be of the correct polarity as it approaches the poles of the field magnet. The usual practice is to have these poles hollowed out so that the armature may revolve within them, thus utilising practically the whole of the magnetic flux. To build a motor of this type would mean some machining, so a modification is given where this is avoided by allowing the armature to revolve outside the fields. Later on, perhaps, the amateur could obtain a set of castings ready machined, and from them build a motor on more business-like lines.

Simple Motors with Wound Armatures.—The iron parts are made from strip iron such as is supplied for bent iron work, though very stout tin would serve. The iron can be obtained very cheaply of several gauges and widths, and is of excellent quality. That used in the present instance is $\frac{3}{8}$ in. wide and $\frac{1}{32}$ in. thick (No. 22 gauge). It is easily bent with a small pair of pliers, but should be kept as flat as possible. Two motors are illustrated, figs. 38 and 39, one with four and one with six poles to the armature, the field magnet being identical in each. After deciding which type is to be made, as many pieces of iron as will be required may be bent to the shape as shown in the drawings, fig. 40 (*a*). The centre of each is marked and a hole drilled through. That in the piece which is to form the field magnet can be about $\frac{3}{16}$ in. diam., and this piece also requires two smaller holes for holding-down purposes. The holes in the pieces forming the armature should be a tight fit on the spindle. The writer used as spindles some round wire nails. They came from an old packing-case, and were $1\frac{1}{2}$ in. long and exactly $\frac{1}{16}$ in. diam., this being much thinner than the usual $1\frac{1}{2}$-in. nail. They were carefully straightened, the heads cut off, and the ends worked up to nice points. This was done in the same manner as the pivots in the Morse

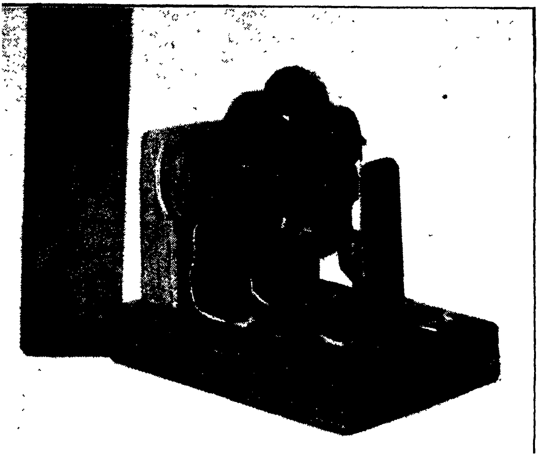


Fig. 38.—Simple Motor with Six-pole Armature.

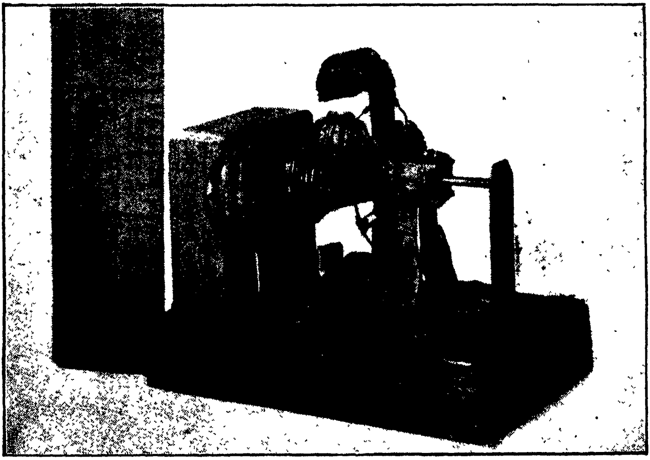


Fig. 39.—Simple Motor with Four-pole Armature.

sounder instruments. The surfaces of the iron round the holes were then "tinned" and the whole armature assembled and stood on a piece of wood face downwards. A little flux was next applied to the tinned portions and a blow-pipe flame soon caused the solder to run. Before this had time to set a little manipulation put everything in its correct place, and the armature then had the appearance as shown in the sketch, fig. 40 (*b*). Of course, the upper iron will need to have its ends bent a little forward in order that all the pole faces

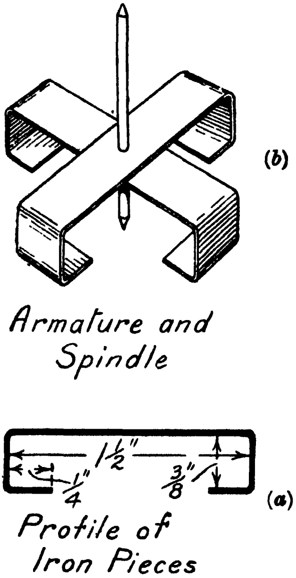


FIG. 40.—Ironwork for Simple Motors.

may come in the same plane. The winding can now be taken in hand. All the iron surfaces likely to be touched by the wire must be carefully insulated by strips of thin paper stuck down with a touch of varnish, the edges receiving special attention. The gauge of the wire is not of great importance except that it should not be too small, or greater voltage will be required to force sufficient current through. The gauges used by the writer gave excellent results. The field received 60 turns of No. 24 D.C.C. on each pole, care being taken to reverse the direction when winding the second in order to produce a N and S pole. A few inches should be left at beginning and ending for connections, about 4 yards in all being sufficient. The armature was wound with No. 26 S.S.C., each pole receiving 60 turns and all being wound in the same direction. This latter is important, and so is it to distinguish between the commencing and finishing ends of each pole. The writer made this simple by allowing about 1 in. at start and 2 ins. at finish. All the ends should be carefully cleaned of insulation, and then the commencing end of one pole twisted up tightly to the finishing end of the next, and so on all round. This will leave the same number of connections as there are poles, and they will presently be connected up to the commutator.

A commutator is usually the amateur's bugbear, and many suggestions for a simplified form have been given. The writer believes the method to be described to be original; but it certainly is extremely simple and produces a first-rate commutator. Two are illustrated separately (fig. 41), and no difficulty should be experienced. The wooden centre is a piece of curtain rod or, as it is known in the trade, a "dowel." They may be obtained at any oil shop and are about 4 ft. long and ⅜ in. diam. Cut off a piece ½ in. long, and very carefully mark the centre at each end. Now with the same drill that was used to drill the armature irons, drill about halfway through from either end. This will ensure the hole being central throughout its length. Now slip the wooden centre on the spindle and spin the whole, armature and commutator, between the finger and thumb. If the wooden centre wobbles, scrap it and make another; but if reasonable care has been taken matters will be quite satisfactory. Next, mark off at either end four or six marks, as the case may be, for the metal portions. No difficulty should be found in marking off the four spaces by eye, and a useful tip for marking the six is to stand the wooden

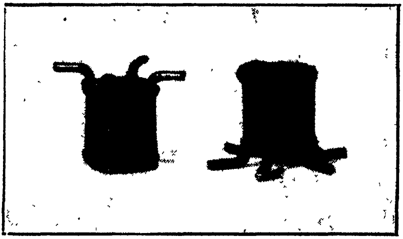
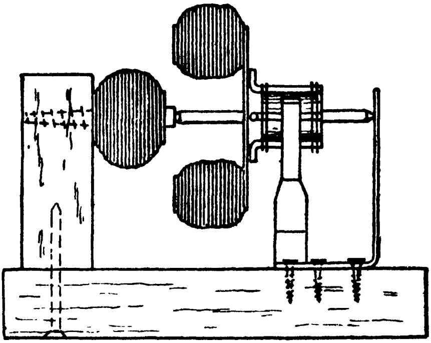
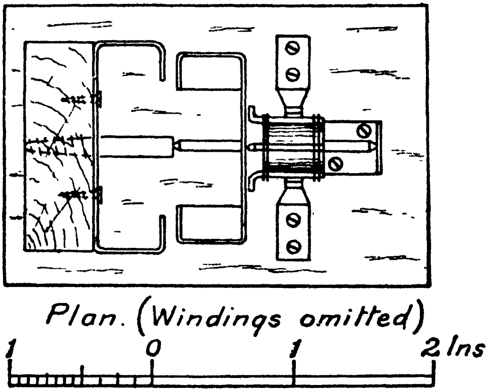


FIG. 41.—Two Simple Commutators. (1/1.)

centre on a hexagonal nut of about the same size. The angles of the nut will give the six points exactly true. Now carefully make shallow cuts with a fine saw, lengthwise, keeping them parallel and equally spaced. Trim up these cuts to a V shape with a three-cornered file, and the centre is complete. To make the bars, cut off a sufficient number of pieces of thick copper wire $\frac{3}{4}$ in. long. The author used No. 16 wire; but whatever gauge is used, the wire should be sufficiently thick to stand out well from the slots. One end of each of these pieces is bent up at right angles, the short limb being about $\frac{3}{16}$ in. long. The commutator may now be assembled. To do this, lay a copper bar in each slot, all the turned-up portions being at one end, and temporarily hold them in position by binding a short piece of thin wire round. Now lash them on by binding round each end two turns of strong carpet thread and tying tightly, being careful not to make a "granny" knot. Take off the temporary wire lashing, and, after adjusting the copper bars and thread, touch round with varnish, keeping the centre portion clear, and set aside to dry. The commutator will then be found to be quite strong and, what is of equal importance, true and well insulated. It can now be finally placed in position. First cut a small circle of stout, brown paper about $\frac{3}{4}$ in. diam., pierce a small hole through its centre, varnish it on both sides, and slip it on the spindle, sticking it to the backs of the armature irons. Now smear a little varnish on the spindle and slide the commutator on, pushing the turned-up ends of the copper bars against the paper circle so that the projecting ends of the bars come midway between the armature poles. The joined ends of the armature windings may now be secured to the upturned ends of the bars with just a touch of solder. The armature now being complete, we may turn our attention to the baseboard. This, as will be seen from the illustration (fig. 42), is a very simple affair, the upright portion being nailed from below. Screw on the field magnet, and then through the large hole in its centre screw into the upright a 1½-in. No. 4 or 5 wood screw. Now take it out again, for it has made its thread in the wood, cut its head off, and in the end surface so produced make a small dent, either with a small drill or a sharp centre punch. The screw can now be put in again with a pair of pliers, letting it go just so far that when the front end of the armature spindle is placed in the dent the armature pole faces just clear the field magnet faces. It will be found that the pointed end of the wood screw projects about ¼ in. through the wooden support. This may be left, but the writer cut it off and made a cross-cut in the end with a fine saw. This makes a very convenient method of adjusting the play of the armature spindle, as a small screwdriver will cause the screw to move in or out as desired. The back bearing is a piece of iron or brass strip bent up and provided with two holes in its foot for fastening to the baseboard, and a dent



Elevation



Plan. (Windings omitted)

FIG. 42.—Plan and Elevation of Simple Motor.

for the back centre at exactly the same height as the front bearing. This back bearing may now be fastened in place and the armature put into position, the bearings being so adjusted that the armature can revolve freely but without any possibility of slipping out. Now come the brushes. These are made from two L-shaped pieces of brass, to the upper ends of which are soldered strips of springy brass foil about $\frac{1}{8}$ in. wide in such a fashion that when the lower ends are fastened to the base the tops of the foil strips extend just a trifle higher than the spindle. If it is found that the feet of the brushes are likely to touch the foot of the back bearing, the upright limbs must be bent out a little beyond the right angle. It is also advisable to bend the extreme ends of the foil outwards a little so that there is no risk of their catching in the commutator bars. Connections may now be made and a trial run taken. One end of the field winding goes to a terminal, the other to a brush, and the other brush forms the second terminal. One bichromate or dry cell should produce a good speed, though two in series are better.

The armatures of these motors could, of course, have many more poles than six, although the whole dimensions would then have to be much greater in order to provide room. The commutator would also require a bar for each pole, and it will be found that while the four-pole has dead positions, and is consequently not self-starting, the six-pole rarely comes to rest at a dead position, and one with more poles would always be self-starting.

Should the amateur be ambitious enough to contemplate a larger and heavier motor of the same type, he might use stouter and wider iron, but then would of necessity be bound to wind on much more wire, and this possibly of heavier gauge. It is necessary in any case to have the field coil wire one or two gauges heavier than that on the armature, as here there are more paths open to the passage of the current, as the maker will discover if he will trace out the connections.

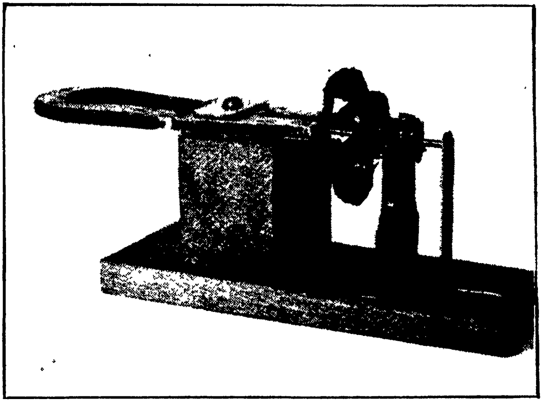


FIG. 43.—Simple Motor with Permanent Field. (½.)

Motor with Permanent Field (fig. 43).—This is simply a variation of the last, the field being produced by a penny horseshoe magnet. The armature is exactly the same except that the wire on it is a little finer. The spindle and front bearing must be of brass, hard for preference, as iron so close to the magnet poles would certainly weaken the field. Results with this type are not so good as with a wound field.

Reference may here be made to the moving coil instruments, a type of which is described in Chapter IV. and another in Chapter VIII., the latter being used for obtaining definite measurements. These instruments, as was stated earlier, are really electric motors, and the student will notice the resemblance still more when he comes to make up a set of materials into a motor, although an electro-magnet will then replace the permanent one in use here.

CHAPTER VI

INDUCTION

THIS chapter deals with an extremely important section of electrical work, for a whole host of indispensable apparatus and appliances depend for their action upon this phenomenon. Several forms simple enough for the amateur to construct are therefore described, although, unfortunately, many of great utility are quite beyond the beginner, involving as they do the preparation of such items as very efficient permanent magnets, and also the machining of large masses of iron; besides in the case of dynamos the necessary driving power. Sufficient apparatus is described, however, to provide the student with plenty of scope for experiment.

Induction of Currents in a Coil of Wire.—The following apparatus should be made and its performance carefully studied, as it will serve to demonstrate the principles of induction and the action of several forms of instruments. Two bobbins are constructed and wound as illustrated in figs. 44 and 45. The precise size is not of great importance, although those described gave very good results indeed. The wooden flanges were cut from American whitewood ¼ in. thick. This is easily done with a fretsaw, and if the reader has a lathe, a light skim up will produce a neater finish. The tube joining the flanges is cut from a cardboard postal tube and glued into place. A coat of varnish over the whole will provide a good finish and serve to stiffen. Two bobbins should be made exactly similar. One is wound with about ¼ lb. of No. 32 S.C.C. wire, and the other with the same amount of No. 20 S.C.C. These gauges of wire should be followed as closely as possible, the only deviation being, that finer than the No. 32 or thicker than the No. 20 might be used. The exact quantity is not of great importance, and if the bobbins are filled it will be just as well. Less wire, however, should not be used. An iron core is necessary and a piece of round

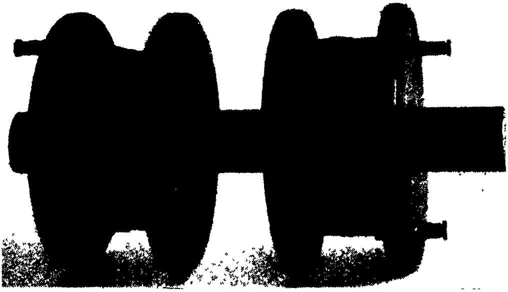


FIG. 44.—Coils and Iron Core for Induction Experiments. (½.)

iron large enough to slip comfortably into the tubes and 5 or 6 ins. long should be obtained. Cast or wrought iron, or even mild steel, will serve (fig. 44). A pair of bichromate cells, freshly made up, will provide current, and a sensitive galvanometer is necessary for the detection of the induced currents. The galvanometer should be as sensitive as possible, the moving-coil type being excellent for the purpose, though it will be found that the horizontal form described in Chapter IV. will do if the high resistance winding is used. If the reader has a telephone receiver, this will form an excellent detector, except that it fails in one respect; that is, it does not indicate the direction of the flow of the current. Other apparatus necessary to complete the set for these experiments would include a bar magnet (permanent) as powerful as

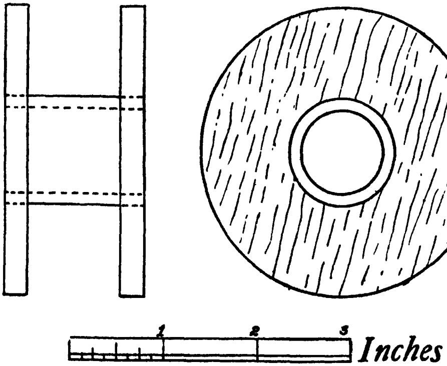


FIG. 45.—Construction of Bobbins for Induction Experiments.

can be obtained, and a much larger bobbin of fine wire; large enough in fact for the small bobbins just described to slip inside. Such a bobbin is used in the graded voltmeter described in Chapter VIII. (fig. 54), so that if the amateur makes that now he will have a piece of apparatus in reserve. The measurements given were partly chosen in order that this might be possible. The experiments should be conducted somewhat as follows:—Take the bobbin of fine wire and connect it directly to the galvanometer, while that with the thick wire is connected to the cells; and it is just as well to introduce into this circuit some form of switch, the Morse key already described serving admirably. This will enable the current to be applied momentarily or continuously as desired.

Suggested experiments:—

(*a*) Place the two bobbins one on the other (without the iron core) and pass current. Note deflection of galvanometer needle on making and breaking contact. It may be just possible this will result in failure, as the induced currents so produced are very weak indeed.

(*b*) Repeat, using the iron core, noticing the increased strength of the induced currents and their reversal on breaking contact.

(*c*) Vary the positions of the bobbins on the core, noting any variations in strength of currents.

(*d*) Use the large bobbin with the galvanometer in circuit and, while allowing current to pass continuously in the small bobbin of thick wire, place it within the larger and then withdraw it. Note deflection of needle on entry and removal, also reversal.

(*e*) Using the small bobbin of fine wire in circuit with the galvanometer, place one pole of the permanent magnet within it. Observe deflection of needle on entry and removal and also reversal. (Unless the magnet is powerful and galvanometer sensitive, this may fail.)

The telephone receiver may be used in place of the galvanometer, and a click in it will denote the passage of current, though, as before stated, no indication of the direction of flow can be obtained, neither will there be any indication as to whether the induced currents are continuously flowing or only momentary.

Sufficient data have now been given to enable the student to understand the working of an induction coil such as is used for sparking purposes or, in small and modified forms, for medical purposes; these latter being generally known as shocking coils. Before passing on to these, it may be mentioned that our arrangement of two coils of wire on a common iron core is a model of the much-used transformer of such great utility in alternate current work. The coils may be side by side, as in our experiments, or wound one over the other. Such transformers would be of no value with continuous currents, for, as we have seen, induced currents are only produced at the moment of make and break of the primary current. This leads us directly to the induction coil, where we have two coils of wire, an iron core, and a more or less mechanical apparatus for making and breaking circuit as rapidly as possible in order that the induced currents may follow one after the other with as little interval as possible.

A Shocking Coil (fig. 46).—This form of induction coil is described first as being simple to construct, and not requiring any great outlay for materials. The form illustrated in fig. 47 is provided with an arrangement for regulating the strength of the induced, or secondary, currents. This can be omitted, but is of course an added advantage. The iron core is composed of a bundle of thin iron wires 3½ ins. long and sufficient in number to make up a total diameter of ¼ in. The writer used hairpins, carefully straightening them, and, after cutting to the right length, annealing them as described in the section on electro-magnets. They were then cleaned up by rubbing with emery-cloth and finally bound up tightly with narrow tape—bandage fashion—and given a coat of varnish. One end of the core was passed through the hole in the wooden upright, keeping it a tight fit and securing with varnish. It was next wound with two close layers of No. 24 S.S.C. wire, the ends of which pass through holes in the upright. This forms the primary winding and, if the secondary is to be a fixture, must be carefully insulated with three or four layers of waxed or varnished paper. In the present case the secondary was wound on a

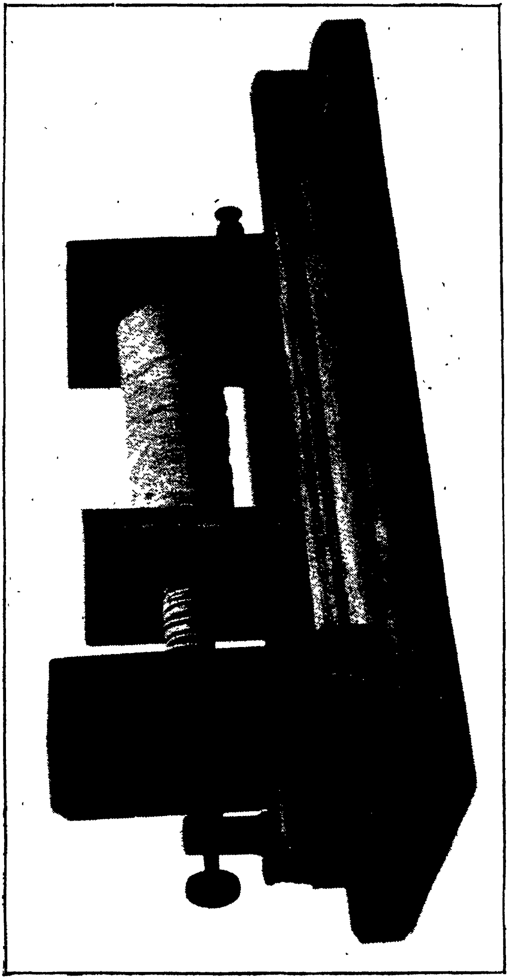


FIG. 46.—Shocking Coil. (½.)

paper tube secured to the end pieces as shown, this being of sufficient size to allow it to pass easily over the primary. The tube was made as described in the paragraph on the solenoid, using of course a suitable mandrel. The wire used was No. 36 S.C.C., six layers being put on, although it would have been better, perhaps, to have used finer—No. 40, for instance. The ends of this are fastened to terminals on the outer wooden cheek; and it will be seen by reference to the illustration that the secondary winding can be slid up and down over the primary, just as in our experiments we could vary the positions of the bobbins on the iron core.

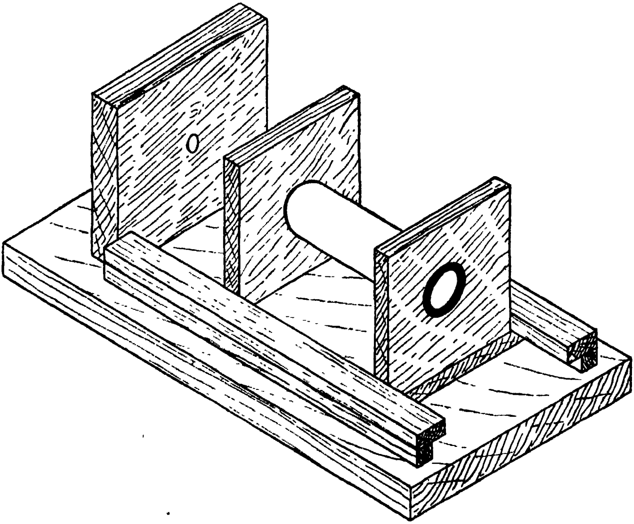


FIG. 47.—Isometric View of Woodwork for Shocking Coil. (⅛.)

Now for the contact-breaker. This consists of two parts: the armature with its spring and contact and the contact screw. The spring is a thin, but fairly stiff, piece of brass soldered or riveted to a right-angled piece of brass for support, while the armature is the head of a fairly large wire nail riveted on. It is clear that the fitting must be so arranged that the armature comes exactly opposite the end of the core, and when at rest it should be about $\frac{1}{8}$ in. from it. The contact on the spring is a scrap of silver soldered on rather nearer the armature than the support. The contact screw can be adapted from the contact pillar from an old electric bell, if available, or it might be a right-angled piece of brass carrying a small brass screw, which must move stiffly and be silver-tipped. The two silver contacts must of course meet one another. Connections are similar to those in the electric bell. The handles through which the secondary current reaches the patient are made from short lengths cut from an old cycle pump (metal, of course) with long flexible leads soldered on. When administering a shock, the secondary should be withdrawn to its furthest extent and gradually advanced as the person can bear. One bichromate or dry cell should produce quite good enough effects, and of course the contact screw can be adjusted to secure the best results.

A Spark Coil.—Most amateurs show great eagerness to build a spark coil, little knowing the difficulties that will beset them. It is not by any means beyond the beginner to construct such a coil, but it must be remembered that patience and extreme thoroughness in every detail are required. For the amateur's guidance, and as an insight into such work, instructions are given whereby he can make up a coil which should give at least a ¼-in. spark, though by excellent workmanship that length may be increased to a good ⅜ in. Those who are ambitious enough to attempt something greater are strongly advised to consult the "Model Engineer Handbook" No. 11, where they will find explicit instructions and specifications for coils up to 6-in. spark. The various portions will be described in order, and construction should not vary much from the description given. The *core*: this must be of iron wires, 5 ins. long and sufficient to form a tight bundle a good ½ in. in diameter. The wires must be perfectly straight and well annealed. They are best bought for the purpose from one of the well-known dealers in such goods, and should be No. 22 gauge. The core must be well insulated from the primary, and a very convenient and safe method of doing so is to bind round it a length of inch-wide tape, bandage fashion, pulling it tight all the time and finishing off the ends by stitching. It may next be immersed in melted paraffin wax till saturated—that is, till no more air bubbles appear. Now the *primary* can be wound on. This should be two close, even layers of No. 18 D.C.C. (¼ lb. being about right), and the winding should be carried to within ½ in. of each end of the core. A few inches should be left for connections, and the two ends bound tightly to the core with fine twine or thread. Now comes one of the most important parts of the whole coil, and one of the chief seats of failure. This is the insulation between the primary and secondary windings. Even in such a small coil the potential of the induced currents is very great, and a weak insulation here will certainly be fatal to successful working. Probably the best method for the amateur is to cover the primary with a couple of layers of linen tape in the same way as the core was treated, only being careful that the laps of the outer tape do not coincide with those of the inner. A prolonged soaking in really hot wax will complete this stage. The *secondary winding* is the next consideration, and, as before, insulation must be the great aim. It will not do to trust to simple winding, as was done in the shocking coil, for breakdown or serious leakage will certainly take place. It must be wound in sections, and in the present case two will suffice. These had better take the form of paper bobbins, each containing half the wire necessary. The bobbins must be made by preparing a paper tube just large enough to slip over the insulated primary. If a postal tube of the right size can be obtained, this will do nicely; but if not, a tube must be prepared as for the solenoid, only of course using a mandrel of correct size. The tube should be as long as the primary winding—that is, about 4 ins. Now four cardboard discs must be cut, each having a diameter of 2½ ins. and a central hole large enough to fit the paper tube snugly. The tube should be cut in halves while on its mandrel, and the discs glued on, so that when all is dry two similar bobbins will result. They need well soaking in paraffin wax before use. These must now be wound with No. 36 S.C.C., ¼ lb. to each. It will be advisable to rig up a rough winding apparatus: just a couple of uprights fixed to a firm base, a piece of broomstick or such-like as a mandrel, a nail for axle at one end, and a stout bent wire as crank handle. Care must be taken during winding in one or two particulars; first, both bobbins must be wound in the same direction, the starting end passing through a tiny hole in the disc close to the tube; second, insulation must be carefully maintained all through. If it can be guaranteed that each layer is absolutely flat—that is, no individual turn of wire sinks into the layer below,—well and good. But it will be found next to impossible to get such perfect winding, so it is better to insulate each completed layer with one turn of waxed paper. The author finds thin paper such as is used in typewriters very suitable, as it absorbs melted wax readily, and, being thin, does not occupy too much room. Sheets may be cut into strips just a trifle wider than the space between the cheeks of the bobbins, dipped into quite hot melted wax, and then hung up to dry. One layer of this between each layer of wire will make matters secure, though care must be taken at the edges, as the wire has a way of pulling the paper inwards and so exposing a turn or two of the previous layer. If this happens, a narrow strip of paper must be introduced to make good. When winding is complete, the bobbins must be kept in hot wax till all bubbles cease rising and then set aside to harden. Next slip the bobbins on the primary so that the two starting ends are inwards. These are cut as short as possible, cleaned, twisted together, and soldered. The joint must be made to lie as flat as possible when the bobbins are pushed up together. The wooden ends of the coil may now be put in. They should be of hardwood well soaked in wax, being about 4 ins. square and $\frac{3}{8}$ in. thick. They must each have a central hole large enough to allow the ends of the core to fit tightly, and the whole can now be fitted to a base, the ends being screwed from below. This base may take the form of a shallow box and will contain the condenser. The top of the base should be about 8 ins. long by 5 ins. wide, the coil being placed about $\frac{1}{2}$ in. from one end, thus leaving about 2 ins. space at the other. This will give room for mounting the contact-breaker and terminals. A *condenser* was mentioned. This is an essential feature of a spark coil, and its purpose is to neutralise the effects of self-induction in the primary wire. We shall not trouble ourselves about the why and wherefore of this self-induction, as this can be left for more advanced study. The condenser is composed of strips of tinfoil separated by waxed paper. Obtain two or three sheets of tinfoil from the dealer, and cut out 16 pieces each 5 ins. long by 1½ in. wide. Now cut out 19 pieces of waxed paper each 4½ ins. long by 2½ ins. wide, and proceed as follows:—Lay two sheets of paper on the table, and place a sheet of foil on them so that a ½-in. margin is left on three sides and a projecting 1 in. of foil on the right. Now lay on another piece of paper and then another sheet of foil as before, only this time having the projecting inch on the left. So go on, paper and foil with the ends of the foil alternately right and left, and finally finish with two pieces of paper. You will then have a block with eight ends of foil projecting at either end. Place it between two thick pieces of wood, and put into a warm oven, laying a heavy flat iron on top, and leave there till cold. Remove

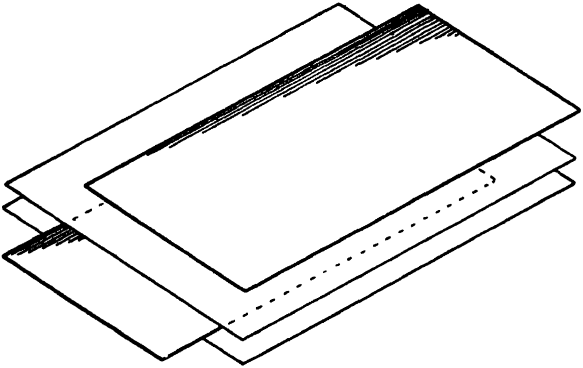


FIG. 48.—Sketch showing Method of making a Condenser.

the pieces of wood and replace them by two thin pieces, and bind the whole condenser round with tape to keep it solid. Connections must now be made to the projecting ends, and a good way is to pierce a hole through and clamp them together with little bolts and nuts and a couple of washers, fastening under a washer at either end a short length of stout copper wire. The *contact-breaker* can be similar to that used for the shocking coil, only much more substantial with a much stiffer spring, and the contacts must be of platinum if possible. Connections are the same as for the shocking coil, with the addition of those from the condenser. These are fastened one to the contact pillar, and the other to the armature support. A couple of terminals should also be provided for the secondary, one on each wooden end. The finished coil should be provided with some protection over the secondary; and perhaps the best the amateur could use will be several layers of waxed paper, the outer one of all being given a couple of coats of black enamel. To work the coil a pair of large bichromate cells will be needed, or, better still, a four-volt accumulator. A greater voltage than four should not be used, as there would be some risk of overheating the primary. It must also be remembered that this coil must not be used for shocking purposes, for although the induced currents produced by it are not absolutely dangerous, they are far too powerful to be pleasant.

The Telephone.—This is another valuable instrument depending entirely upon induction. The modern form is far too difficult for the amateur to construct, all its parts requiring a high degree of workmanship and fine tools. A simple modification is, however, given, which, provided care is taken, will give quite good enough results to demonstrate the principles of the regulation instrument. No instructions are given for fitting up complete stations, this being rather outside the scope of this book; but if the amateur feels so encouraged by his experiments as to be desirous of doing so, he is advised to consult the "Model Engineer" Handbook No. 4.

A Telephone Receiver.—The usual type recommended for the amateur to construct is that known as the "Bell" pattern, where a bar magnet having a coil of wire round one of its poles is used. The writer tried his hand at the simple construction of the "watch" pattern, where a modified horseshoe or ring magnet is used. This enables both poles of the magnet to be utilised, and the instrument described is the result of the experiment. An ordinary horseshoe magnet, as sold at toyshops, was obtained (costing 2d.), and, when purchasing, the author endeavoured to select that which appeared to be most strongly magnetic. Two pieces of soft wrought iron ⅜ in. wide (the same as used for the motors described in Chapter V.), were bent up to the shape shown in fig. 49, the open part being a tight "push fit" on the poles of the magnet.

The upper, doubled-over, parts were kept as nearly as possible on the centre line and both of the same height (½ in.). Little discs of thin stiff card were made, and a slot cut in them for the upstanding iron to pass through. They were then pushed on and secured with varnish, and at the same time a couple of layers of thin paper were wound round the iron between the discs to serve as insulation. These little bobbins were wound with the finest wire the writer had by him—No. 42 S.S.C.,—each receiving the same amount, as near as could be judged (700 turns on each). They were wound in opposite directions, just like an electro-magnet. When placed on the magnet poles a little scrap of brass was jammed between the poles to act in some measure as a screen, and so cause the magnetic lines of force to pass upwards through the extensions. A ring of wood was then made, this being 2⅝ ins. external diam. and 1¾ ins. internal, and just so thick that, when fitted up, the tops of the extensions came $\frac{1}{64}$ in. below the level of the top. Slots were cut

FIG. 49.—Magnet and Coils for Telephone Receiver. (⅗.)

to accommodate the legs of the magnet, and a thin wooden bottom was fastened on with fine brass screws. When all was together, the pole pieces (extensions) occupied a central position in the inside of the ring. Two small terminals were fitted and the ends of the bobbin windings taken to them (fig. 50). The next consideration was the diaphragm. This consists of a disc of very thin iron, varnished on each side, and known as ferrotype iron. It can be obtained from any photo-

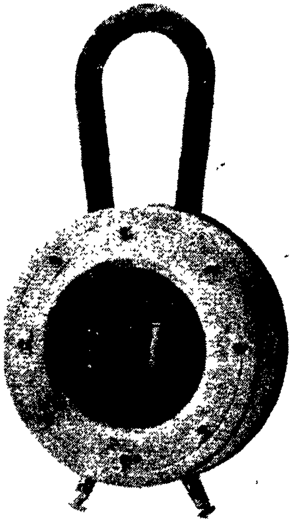


Fig. 50.—Telephone Receiver (cover and diaphragm removed). (½.)

graphic dealer in fairly large sheets at 3d. per sheet. The writer had by him an old diaphragm which came from a damaged receiver, so was saved the trouble of making one. The metal can be cut quite easily with a strong pair of scissors, but great care must be taken not to buckle it, or it will be useless for our purpose. The disc should be 2⅛ ins. diam. and has to be fastened down to the ring as tightly as possible, and this was managed as follows:—A disc of wood $\frac{3}{16}$ in. thick was cut ¼ in. larger in diameter than the ring. It had a ½-in. hole in its

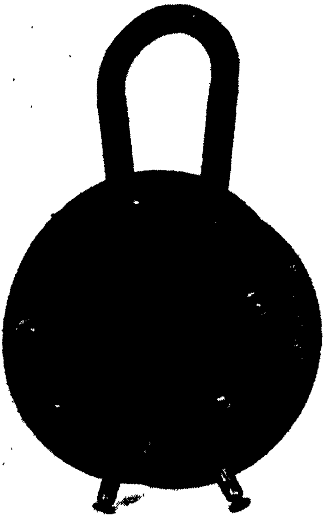


FIG. 51.—Telephone Receiver (complete). (½.)

centre for sound waves to pass, and eight equally spaced holes near its outer edge to take small brass round-headed screws. The circle on which they were marked was $\frac{1}{8}$ in. larger than the diaphragm. The whole—ring, diaphragm, and cover—was then placed together and screwed up; placing the diaphragm on the ring, a stout brass washer between that and the cover at every screw, and lastly a thin washer under the head of each screw (fig. 51). The instrument was complete, and a test was made. A tiny cell was set up, as described for the moving-coil galvanometer, and a brisk little click in the telephone told that all was well. On actual test, in place of a regulation receiver, the voice was quite audible though, as was expected, not so loud as with the commercial instrument.

Dynamos.—These come in the group of electrical apparatus depending for their action upon induction. Their construction is not entered upon in this book, for, as was previously mentioned, this is a little beyond the beginner. Later on he might obtain a set of materials upon which the heavy machining is already done, and try his hand at making up a machine. He will find a wealth of information in the "Model Engineer" Handbook

CHAPTER VII

ELECTROLYSIS

THIS is an important branch of electrical work, though the amateur is hardly likely to dip very deeply into the subject, as its applications are more limited than other electrical effects. The apparatus the student can make in order that he may experiment a little are few and hardly of a constructional order, but more a matter of manipulation, the reactions belonging, as they do, rather to the realms of chemistry than electricity. Indeed, for a proper understanding of this subject, a fair knowledge of chemistry is required. A few hints are given to enable the student to familiarise himself with one or two phases of the subject.

The Analysis of Water.—This was probably the earliest experiment performed in electrolysis, and the student may care to work the same himself. The process consists in passing a current through water and collecting the gases liberated during the action in suitable tubes. The reader is no doubt familiar with illustrations of the apparatus as figured in works on chemistry and elementary electricity. The vessel used must have an opening at the bottom; and the writer made a very good piece of apparatus by using a large glass funnel with the spout portion cut off. This was done by filing a nick all round, using a three-cornered file, and then laying the tip of a red-hot poker in the mark so formed. The glass will immediately crack along the scratch, and by following up with the poker, the spout and upper portion can be cleanly separated. It is not by any means essential that the stem of the funnel be cut off, and the illustration (fig. 52) shows one left uncut. Two stout pieces of copper wire then had a little strip of platinum foil about 1 in. long and ¼ in. wide soldered to one end of each. Platinum must be used, as the oxygen produced, being in its "nascent" state, is extremely energetic, attacking any other metal and so spoiling results. The quantity mentioned will cost about 1s., and need be only very thin. These strips must be introduced into the small end of the vessel so that the soldered joints are about ¼ in. within the opening. They should be about ½ in. apart, and parallel. While supported temporarily in this position by means of a disc of cork, which also fits the hole in the glass, pour in sufficient thin plaster of Paris to embed them so far that the soldered joints are covered. When the plaster has set and is quite dry, a little hot paraffin wax is poured in. This will fill the pores of the plaster and make a plug impervious to water. The whole contrivance can now be mounted on a suitable wooden stand with the wires brought out into a convenient position. The water used must have a few drops of sulphuric acid added to it to render it conductive, and each platinum strip must have stood over it a small tube also filled with water. Small specimen tubes 3 or 4 ins. long do very well. In case the experimenter does not know how to get the tubes upside down while still full of

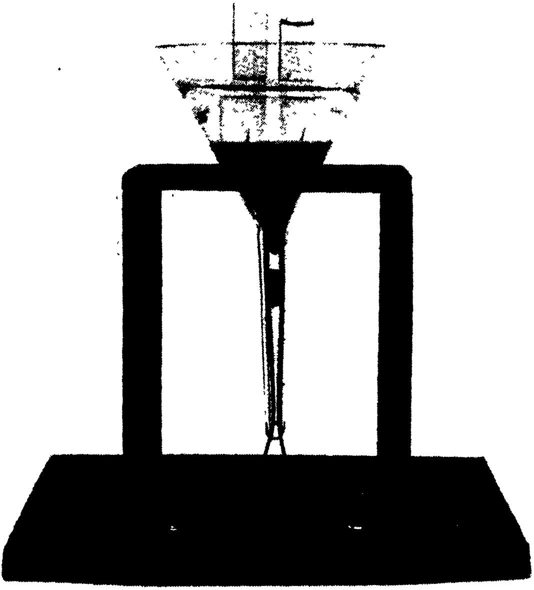


FIG. 52.—Apparatus for Electrolysis of Water. (¼.)

water, this is the method. Fill them at the tap, place the thumb over the mouth of a tube, and then lower it in the water. Take away the thumb, and the tube remains full as long as its mouth is below the surface. A current from two bichromate cells should now be passed, though four cells will cause matters to proceed quicker. Streams of tiny bubbles will rise from each electrode and gather at the upper ends of the tubes; and it will soon be seen that twice as much gas is being evolved from the platinum connected to the zinc of the battery as is rising from the other. The two gases could of course be collected in the same tube if it were wide enough to cover both strips; and it needs little imagination to follow how this apparatus could form a means of measuring the amount of current that has passed during a certain time. A meter based on this idea is actually used on supply mains, though, of course, the tube has to be carefully calibrated in order that the gas collected may be a correct indication of the watts consumed.

Electro-plating. — This is a very important adaptation of electrolysis to commercial use. Instead of water, a solution containing the metal to be deposited is used, and instead of platinum electrodes, a sheet of the same metal as is in solution is connected to the positive side of the cells and the article to be coated to the negative side. In practice, however, when plating is done on a large scale, a dynamo of low voltage generally replaces cells. The amateur will find that for his experimental work a Daniell cell is preferable to a bichromate, as a better coat of metal is deposited when a weak but steady current is used. He might try his hand at copper-plating as being cheapest and simplest. Prepare a strong solution of copper sulphate and add a drop or two of ammonia. Pour the liquid into a wide glass vessel, and get a strip of copper for the anode, as it is called. This may be of any convenient size, and is connected to the positive side of the cell. The article to be plated—a key, for example—must be thoroughly cleaned by dipping in weak acid, then in soda solution, and finally rinsing in clean water. It can then be suspended by a wire from the negative side of the cell so that it is an inch or two from the anode and completely immersed. On current being passed for ten minutes or so a good coating of copper will be deposited all over it, and this may be rinsed in water and polished. This idea is also used as the basis of a current consumption meter, both plates being of copper and immersed in copper sulphate solution. The gain in weight of the cathode (the plate connected to the negative side) represents the watts consumed. The amateur can experiment later, using other metals than copper, but he will find his results not up to professional work, as in the trade various modifications are introduced which are beyond his scope.

Accumulators.—These important cells naturally find a place in this section of the student's work, and he probably knows better by now than to call them storage cells, as is so often done. They do not store electricity in the same sense as a cistern stores water, or a gas-holder stores gas; but the substances of which their plates are formed undergo a change in composition by electrolysis during the passage of current through them, and these new products will, if allowed, revert to their former state and so produce current. The chemical actions upon which this depends are rather complicated, but can be briefly expressed as the oxidation of lead by the electrolysis of sulphuric acid. Many amateurs have constructed accumulator plates for themselves; but, frankly, the author does not advise the reader to waste time or material by so doing. The principle of the plate is a lead foundation supporting a quantity of one of the oxides of lead, the variety of this oxide forming the difference between a positive or negative plate. Plates can be obtained ready-made and are produced by scientific methods and special machinery which are the results of many years' study and experience. The writer has made many plates, trying many modifications, but finds their efficiency low and their life terribly short when compared with the commercial article. The amateur who wishes to experiment in this direction is referred to the "Model Engineer" Handbook No. 1, where he will find full details of plate-making as well as making-up and charging accumulators.

Fig. 53 shows a lead grid and a pair of completed plates as constructed by the author. The grids were cast in a two-part mould of gunmetal. The inner surfaces of the metal had deep cuts made in them by means of a shaping machine, and the pouring hole at the top forms the lug of the grid. The plate on the left is a positive, the grid being filled with a stiff paste made of red lead and sulphuric acid (1 in 4 of water). The paste is pressed in as firmly as possible; in fact, it might be hammered in (taking care not to burst the sides of the grid) while the grid is resting on a thick piece of plate glass—filling one side at a time. The

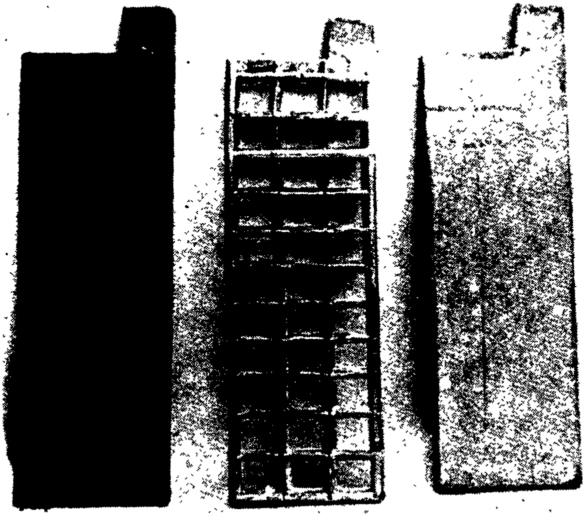


FIG. 53.—Accumulator Plates and Grid (½.)

other plate is a negative. This is pasted in a similar manner, but using litharge instead of red lead. When the paste is quite set, the negative plates are immersed in a strong solution of chloride of lime for some hours and then thoroughly dried in a warm oven.

As before stated, these plates give fairly good results, but soon get soft and friable. The commercial article is produced under very great pressure, and the grids themselves are of far too difficult a pattern for the amateur to reproduce. Summing up, then, by far the better plan is for the student to get a 4-volt accumulator ready made. A really reliable cell of 20 amp.-hours' capacity in a celluloid case will cost about 10s. and with reasonable care will give many years' service. If the reader does not object to the weight and slight inconvenience, he might obtain cells in open glass boxes. These are a little cheaper than the portable form, and for experimental work really preferable as they retain their charge better and are easily inspected or cleaned out. The writer has some such cells which have been in constant use for over twelve years. They were made by the E. P. S. Co., and were originally in lead-lined teak boxes, these latter being replaced by glass boxes when the wood began to get a little rotted by the acid.

With small cells up to the capacity mentioned above, the amateur can quite easily do his own charging, though it must be confessed that if there are facilities for charging near, that is the better method. Either the double-fluid bichromate or gravity Daniell cells are suitable. It must be remembered that each individual accumulator cell requires an applied voltage of almost three in order that it may be charged properly, so that three double-fluid bichromate cells would be necessary to charge a 4-volt accumulator; while if using Daniell cells, six would be needed. The amateur will find it a good plan to have two such accumulators and let one be on charge while the other is in use, setting up the correct number of gravity cells for the purpose. The small amount of current these cells produce will allow the accumulator to be continuously on charge night and day without harm; and it will be remembered that the necessity for continuous work is one feature of these cells.

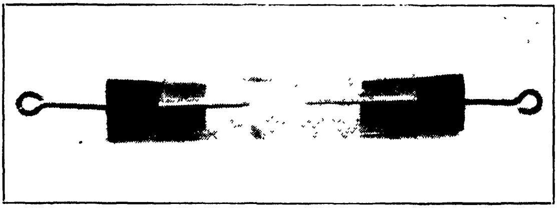


Fig. 54.—Polarity Indicator. (⅔.)

While on the subject of electrolysis it may be interesting to the student to make what is known as a *polarity indicator.* Questions are often asked about these, and some little mystery seems to surround them. Generally speaking, they consist of some chemical or other, which, upon current being applied to it, changes colour at either the positive or negative wire. The chemical may be in solution in a glass tube, or it may be in a dry state in the pores of unsized paper which has been saturated with it and allowed to dry. In this latter case the paper must be wetted before the test is made. A simple form can be made as follows:—Dissolve in a little water a small crystal of sodium sulphate. This is a common medicine in most households under the name of "Glauber's salts." When dissolved, add a drop or two of phenolphthaleine. This is easily obtained from any dispensing chemist as he uses it very frequently, and if the reader is a customer would most likely make no charge for such a minute quantity. Now get an inch or two of glass tube about ⅜ or ½ in. diam., fit it with a couple of good corks (rubber for preference), and pass through each a short length of fairly stout German-silver wire. Fill the tube with the prepared solution, and push the corks in tightly so that the inner ends of the wires project about ¼ in. into the liquid (fig. 54). The solution is colourless now, but on current being applied to the wires, a pink coloration begins to form round the wire connected to the negative source of supply, but on shaking the tube this will disappear.

CHAPTER VIII

ELECTRICAL MEASUREMENTS AND MEASURING INSTRUMENTS

MENTION has been made several times in the previous chapters of volts, amperes (or amps.), watts, and ohms. These, as the student probably knows by now, are the units of electrical pressure: quantity, power (rate of doing work), and resistance respectively. It is extremely important for the student to get a perfectly clear understanding of these and their relation to each other; and also that he should use these measurements throughout all his experimental work. This chapter is devoted, not to a theoretical explanation of the matter, but to a description of apparatus whereby calculations may be made and actual measurements taken.

The beginner's thoughts will probably first turn to voltmeters and ammeters. These instruments, as seen on switch-boards, in laboratories, etc., are usually very expensive, because fine material and workmanship are put into them, and also because their calibration is a lengthy process, and one requiring very precise and careful work. All this, of course, has to be paid for. If the student is desirous of obtaining instruments for himself, he will find small ones on the market at a few shillings each, which will be quite accurate enough for his own private work. On the other hand, he may have a fancy to try his hand at making his own meters, and a study of a few professionally made meters will show him how various are the principles upon which they are constructed. The solenoid, magnetic attraction and repulsion, under various conditions, are all adapted to produce indications of the value of the current passing. There are, again, a few types of more unusual form; but, taking the whole, it will be found difficult for the beginner to reproduce either of them with any great degree of accuracy. There are two forms here described which the amateur may well try to construct, the first being the simpler.

It will be seen to be a modification of the tangent galvanometer (see *Frontispiece*) and is due, the author believes, to Lord Kelvin. Briefly, it is a galvanometer where it is possible to vary the position of the magnetic needle in relation to the coil of wire carrying the current, until the needle assumes a predetermined deflection, and that position indicates the current (either voltage or amperage according to construction) which is passing in the coil. The needle is constructed as described for the simple form of galvanometer in Chapter IV., with the addition of an aluminium pointer fixed at right angles to its length. The needle and pointer move in a case having a glass top, and which is capable of being moved up and down a platform. The case was made from a portion of the case of a cheap alarm-clock. The metal being zinc is well suited, as it is non-magnetic. On the upper surface of the base of this compass-box are marked three lines: one in black ink over the longitudinal centre of the platform, and two in red ink at 45° to the black line. The base is of thin wood covered with white glazed paper, and carries at its centre a piece of sewing-needle upon which the magnet swings. It is also screwed to a small block which fits, without shake, between the bevelled strips at the sides of the platform. Between the base and glass lid of the box is placed a ring of cardboard, also covered with white glazed paper, this serving to support the glass. It should be mentioned that the needle-point is just so long that while the magnet can swing freely there is not sufficient room between its brass cap and the under surface of the glass for the magnetic needle to get displaced (fig. 55). The coil of wire is wound on a bobbin the sides of which are of $\frac{3}{16}$-in. fretwood, separated by and glued to a ring of stout card. A ring of tough paper was also glued to the wood on each side, the inner edge of the paper being snipped and turned into the centre of the ring. This helped to make an extremely strong yet light bobbin. The whole was then given two coats of black enamel. The bobbin is wound with $\frac{1}{2}$ lb. of No. 36 S.S.C. wire, as the resistance must be kept fairly high (fig. 56).

There is no need to go to the extra expense of silk-covered wire, that insulated with cotton serving quite well; the writer having by him that specified, put it to use. Other constructional details can be gathered from the illustrations (fig. 57). As mentioned in Chapter VI., the coil of this instrument is of use in the experiments on induction, and can be readily removed when required for this purpose. A strip of paper must be glued along the front edge of the platform to receive the scale

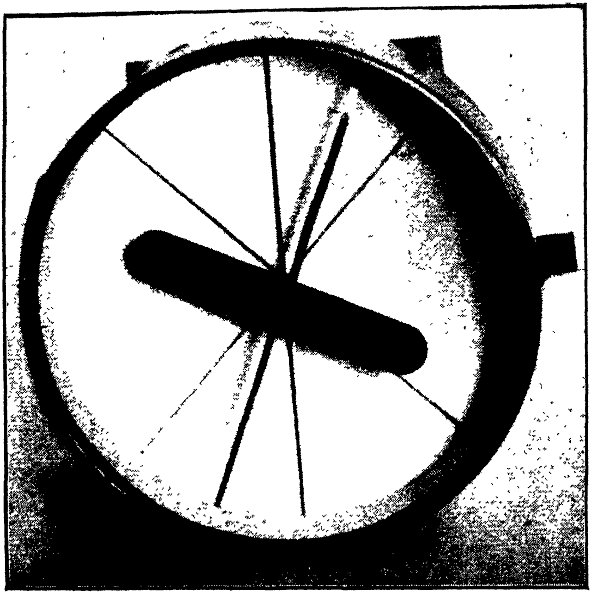


Fig. 55.—Compass-box for Graded Voltmeter. (¾.)

markings, and a little brass pointer overhanging this scale is fastened to the compass-box. To calibrate the instrument would be rather a critical

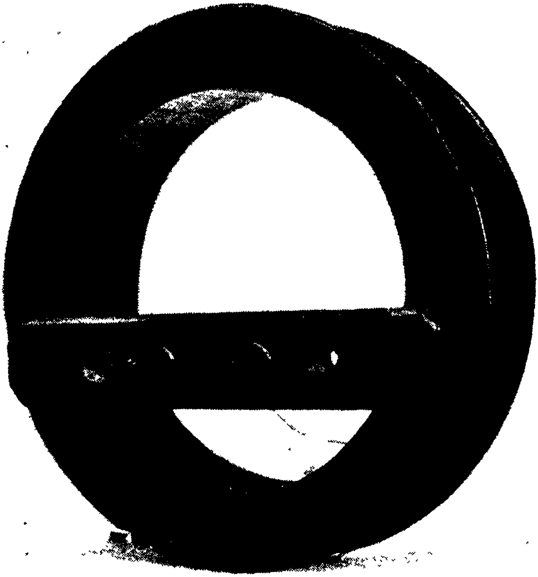


FIG. 56.—Coil for Graded Voltmeter. ($\frac{2}{3}$.)

matter if great accuracy were required, but a very close approximation can be made by using Daniell cells, these giving just a trifle over one volt each. A set of these cells can be made up as described in Chapter III., the number depending on the range required. The cells are connected in series with

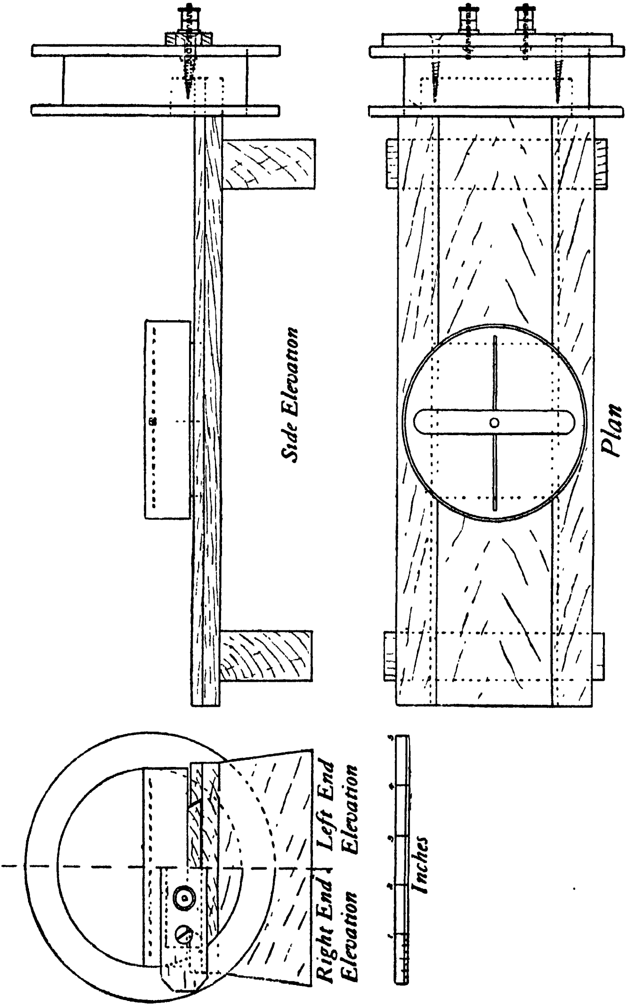


FIG. 57.—Plan and Elevations of Graded Voltmeter.

each other and the coil, the compass-box being at the end of the platform remote from the bobbin. It is then gently slid along till the pointer attached to the needle is resting over one of the red lines. On the paper scale make a mark where the little brass pointer indicates, putting also a number corresponding to the cells in use. Now omit one cell, and repeat the operation; and so on until one cell only is in action. To make matters as accurate as possible the whole of the calibration might now be repeated, only this time joining up the cells in the reverse position so that the needle swings in the opposite direction. If any differences occur in the readings, the mean position should be taken. If the amateur has them, he may use accumulator cells. These will, however, give two volts per cell, the odd numbers being obtained by division of the spaces. The accumulators also should not be used when just charged, as the error will be too great. They should stand idle for a day or two. It should have been mentioned, though possibly the reader will take it for granted, that when using the instrument it must be placed in such a position that the pointer rests over the black line.

To construct an ammeter on similar lines the only difference necessary will be to provide a coil of wire consisting of but one layer of thick wire (No. 18 or even 16). This offers but little resistance, the whole of the current passing in the circuit also passing through the instrument, which must therefore be placed in series with the cells and apparatus in use. The voltmeter, on the other hand, is always placed as a shunt across the circuit. The calibration of the ammeter for the above reason becomes a little more difficult than in the case of the voltmeter. If the student can get a friendly electrician to lend him an ammeter, matters will be much simplified. If he cannot, he must purchase a 2-ohm resistance coil. These are sold wound to various resistances, and, if not required of great accuracy, are quite cheap. At any rate it is a useful piece of apparatus to include in the student's equipment. The only caution to observe when purchasing is to be quite sure that the coil will carry the total amperage the user is likely to require. The writer presumes that 4 amps. will be the maximum current the beginner is likely to use, and so the resistance coil should be a 2-ohm capable of carrying 4 amps. without overheating. If he cares to make this himself, he is advised to purchase 10 yards of No. 16 "Eureka" wire (bare). This will have when cold, as near as possible, 2 ohms resistance, and will safely carry 4 amps. It should be coiled up on a broomstick as tightly as possible, and when released will open out like a spring. It should be looped up to the edge of the bench or a shelf on a couple of nails so that no two adjacent coils touch. For source of current to conduct the calibration there is nothing to equal a couple of 4-volt accumulators of about 20 amp.-hrs. capacity, or over. If the reader does not possess such, he can perhaps borrow them, or they can be hired at little cost. These in series with the ammeter and resistance coil or wire will discharge at 4 amps., because $C = \frac{E}{R}$ or, in words, current (amps.) passing in a circuit equals the voltage divided by the resistance; therefore $C = \frac{8}{2} = 4$. Now, if one cell (not one accumulator) is cut out, we have 6 volts pressure, so we get 3 amps. passing. In the same way 4 volts will pass 2 amps., and 2 volts 1 amp. Smaller divisions can be put in by approximation.

One little alteration the writer would suggest, and one he would carry out if he were constructing another of these instruments, would be to make the front strip of the platform wider, and have the scale on top instead of the edge. This would make more comfortable reading. It will also be noticed that the platform is much longer than is required for the voltage marked. This is because the writer had no idea of the length necessary when the instrument was planned. As it happens, however, this extra length counterbalances the weight of the coil, which would otherwise tend to make the instrument tip up.

The next type of instrument, also a voltmeter, is offered as an attempt to reproduce in a simplified form one of those high-grade instruments on the moving-coil principle. An inspection of the illustration (fig. 58) will show its close resemblance to the moving-coil galvanometer described in Chapter

IV. The great difference is in the method of permitting rotation of the coil, and consequently of providing for the passage of current to and from it. The magnet is from a cheap form of magneto-generator, but in this case is provided with curved pole pieces. This is a great improvement on the type used in the galvanometer, as it produces a much more intense magnetic field. The iron core, the former, and its winding are all similar. No

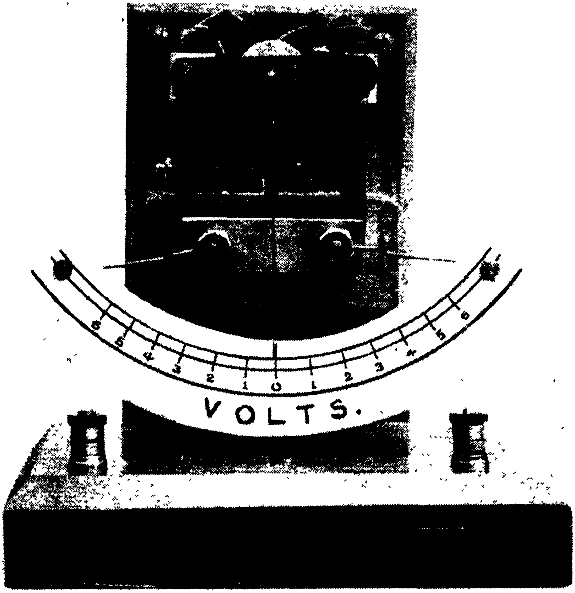


FIG. 58.—Moving-coil Voltmeter. ($\frac{3}{5}$.)

counterpoise is required, the pointer acting as a gravity control for returning the coil to its normal position; and for this reason is of stouter wire than was used in the galvanometer. It may be found that the coil obstinately refuses to assume a truly horizontal position of rest. This may be due to many slight causes, uneven winding and so on, and if very pronounced, it is best to construct another coil; but if only slight, say not more than $\frac{1}{16}$ in. out of level, a little counterpoise may be fitted to the back pivot. This could be of the same construction as that used in the sensitive galvanometer (the third form described in Chapter VI.). It should not, however, be very heavy—just sufficient to bring about the desired horizontal position of the coil. The pointer must then be adjusted to hang vertically, this being the zero position as shown on the scale. Some little dexterity and fine fitting are required in providing pivots and bearings for the coil. In place of the long leads of fine wire left in the previous case, little pieces of hard copper wire are soldered to tiny strips of brass which are lashed to the former, with a layer of paper as insulation between them and the wire. The ends of the former winding are soldered one to each of these strips, and the outer ends of the copper pivots are carefully rounded and made quite smooth. They pass through the ebonite bars supporting the bearings, without touching them, the holes being much larger than the diameter of the wires. Ebonite is used so that the bearings may be quite insulated from each other, and if metal is used this condition must be secured by the use of washers of mica or celluloid. The bearings themselves are strips of stiff copper foil, the ends of the pivots working in dents in them. These foil strips being slightly sprung inwards, prevent the coil pivots from falling out, and at the same time make electrical contact with them. Care must be taken, however, that they are not so springy as to interfere with the free movement of the coil. The ebonite bars are screwed to aluminium supports which themselves are held under the screws used to fasten the pole pieces to the magnet. The use of aluminium is of no particular significance, this being used simply because it was to hand, brass or copper serving equally well. The wire pointer is soldered to the front pivot, which is made a trifle longer than the back for this purpose, and bent to the required shape. The scale can be to the maker's fancy, that illustrated being adopted so that the "works" were entirely visible. The whole instrument might also be mounted in a glass-fronted case on a neat wood base; but, however finished off, it is apparent that the meter must be used in a vertical position.

As the passage of anything like a heavy current at even one volt pressure would be fatal to the coil, a high resistance is placed in series with it. This is best formed of a length of fine resistance wire and must be found by trial. As the reader's coil winding may be different from the writer's, and as the range of the instrument can be varied within fairly wide limits, it is not possible to give definite advice on this point. The writer, making six volts as the maximum reading, used 40 feet of No. 38 platinoid. A proportionately longer copper wire of the same gauge could be used, but the much shorter length of proper resistance wire would probably be cheaper. At any rate a wire coarser than No. 36 is hardly permissible. The estimated amount of wire should be wound non-inductively on a small bobbin and cut shorter and shorter till the pointer swings to its desired limit with the maximum voltage it is intended to use. Once the required resistance is found, the instrument can be calibrated as in the last case, using Daniell cells, and working back cell by cell to one. Zero being at centre, each side of the scale can be separately marked, reversing the connections from the cells at each step; or one side can be marked off from the other. If the instrument is to be mounted in a case, the resistance may be fixed permanently within it.

The writer does not recommend the amateur to attempt to use this simple form as an ammeter as there are some difficulties in the way, the chief being the difficulty of making a shunt of sufficient accuracy and reliability. Ammeters to register at low voltages seem to require exceptional care to be reliable. Having his meters, the student will next require one or two further appliances in order that he may carry out his measurements and calculations more completely; and perhaps that most

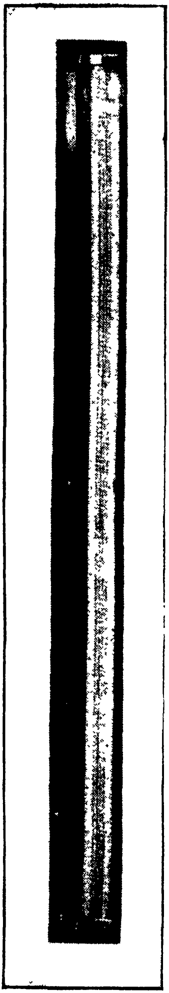


FIG. 59.—Wheatstone or Metre Bridge. (⅛.)

generally useful is the Wheatstone bridge. This piece of apparatus, though simple, is practically indispensable and occupies much the same place in the electrician's equipment as does the fine balance used by the analytical chemist. A great variety of problems can be solved by its means, as the student will gather during his theoretical studies. It has been made in many forms, and that here described is about the simplest, though at the same time it is perfectly reliable for general work; though where exceedingly accurate results are desired, the question of insulation would require closer attention. No information as to its various uses is given, the reader supplying that from his text-book as he progresses.

A Metre Bridge.—As the name implies, it is rather an elongated piece of apparatus, and in many forms, as made professionally, the length is curtailed by certain modifications. In the present case the length will help the beginner to grasp the principles of the apparatus more readily than an involved pattern would do (fig. 59).

Obtain a piece of dry hardwood about 44 ins. long, the width being immaterial, that in the instrument illustrated being 3½ ins. The thickness should be such as to give this base as much stiffness as possible, and two or three battens might be screwed and glued across the width to this end. The writer used a piece of old, dry oak and gave it several coats of thin shellac varnish, rubbing down with glass paper between each, and finished off with a good coat of white hard varnish. Along each end is fastened a strip of brass or copper. These strips should be fairly stout in substance and about ⅜ in. wide. At either end of them a terminal is fitted, and soldered or screwed to them is a length of resistance wire. This can be of practically any of the usual resistance alloys, and the gauge is not material. In the bridge shown No. 22 platinoid is used. It must be bare, quite clean and bright, and stretched taut; and its length between the strips to which it is fastened is exactly one metre. Under it is pasted down a paper scale. This is one metre divided into centimetres and millimetres, two sets of readings being provided, one having zero at the right hand and the other at the left. Scales such as these can be obtained ready printed, and therefore neat and accurate, from any scientific apparatus dealer for a few pence if the amateur does not care about making his own. Fastened down near the back edge of the base is a strip of brass or copper, or even a very stout copper wire (about 10 or 12 gauge), making contact with three terminals. The illustration (fig. 60) will make matters quite clear. This completes the bridge, and the student will find it quite convenient to make contact along the resistance wire by means of a short piece of stout copper wire provided with a terminal. Laboratory forms of the bridge are often provided with a sliding contact or jockey, but this requires very careful fitting to be quite reliable.

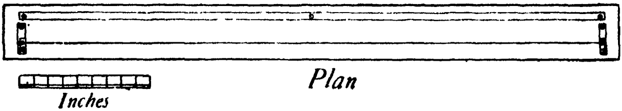


FIG. 60.—Plan View of Metre Bridge (scale omitted).

A necessary adjunct to the Wheatstone bridge is a known resistance. If the reader has made and calibrated an ammeter as described in the early part of this chapter, he will have a 2-ohm resistance ready. He could now proceed to make a 1-ohm coil, another 2-ohm, and a 5-ohm—in fact, any number of whatever resistance he chooses. This work can be done with the bridge, one or two cells—Daniell for preference,—and the most sensitive galvanometer he has. A telephone receiver could replace the galvanometer, but requires some practice to use successfully for this purpose. By making the coils suggested he will be able to set up a good range of resistances by joining them in series or parallel in various combinations.

Coils for such a purpose should be wound non-inductively. This brings us back to our experiments on induction, and also recalls a remark made in the description of the induction coil, as to the purpose of the condenser. In order that the resistances shall be as accurate as possible it is necessary to provide that the current passing shall not be subject to any disturbing factors. Chief among these are alterations in the resistance of the conductor due to heating, and an effect difficult to make clear to the beginner, but which may be likened to a kind of choking; this being produced by magnetic influences. The former factor is minimised to a great extent by using alloys which do not greatly alter in their resistance when heated; and the latter is overcome by making the coil in such a manner that magnetic effects are neutralised. This is done by doubling the wire on itself at its centre, and then winding the doubled wire on a bobbin, starting with the doubled end. This gives, practically speaking, two equal lengths of wire but coiled in opposite directions. When making a resistance coil, then, the amateur should take a little more wire than the required length, find its centre, double it so that the ends come together, and then wind it on a cotton reel or similar bobbin, finishing with the two free ends. Then tests may be made using the metre bridge, and the wire cut shorter and shorter till the resistance is correct. A pair of terminals can then be fitted and the whole coil well soaked in paraffin wax.

The bobbin should finally be marked with the resistance value.

A further piece of apparatus of great utility is a *potentiometer.* This is an instrument by means of which the potential or pressure of a current can be regulated very accurately. It is virtually an adjustable resistance, and, as mentioned in Chapter IV., the rheostat can be used as a potentiometer. The whole current is made to pass through the complete resistance, and the sliding contact enables more or less to be tapped off as required. A separate instrument may be constructed on just the same lines as the metre bridge, except that a terminal at either end of the wire only will be needed. The potential of the cells being known, a contact at a certain spot on the wire will shunt off a proportion indicated by the scale reading. The rheostat might be provided with a scale, though it would not be so easy to determine the exact quantity of resistance included. Finally, it will perhaps suggest itself to the student that the metre bridge itself could be used as a potentiometer. This is quite true, and the only reason for suggesting the construction of a separate instrument is the possibility of needing both when working out certain calculations.

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